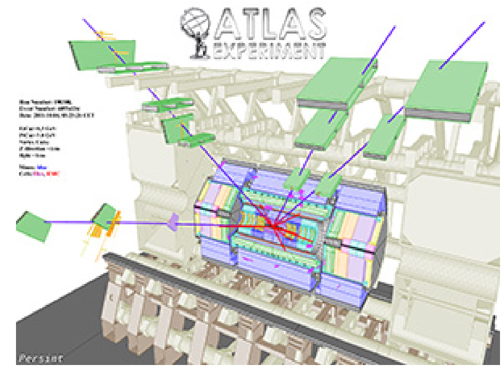
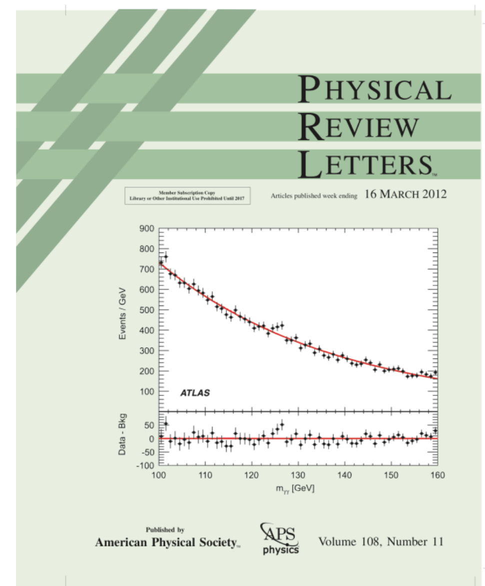
ATLAS physics



Marcel Vos (IFIC, CSIC/UV, Valencia, Spain)



XL International Meeting on Fundamental Physics,

Centro de Ciencias Pedro Pascual, Benasque, May 2012

ATLAS physics

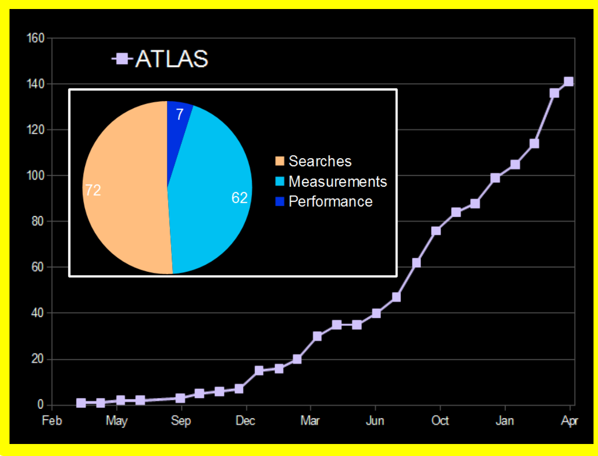
Let's start with all the things that this lecture is not about...

For preparation, operation and performance,
→ see Sergio Gonzalez' talk
For detailed accounts
→ see Fri. and Sat. discussion sessions

In 30 minutes, I can at best hope to deliver a strongly biased summary of 100+ papers

Outline:

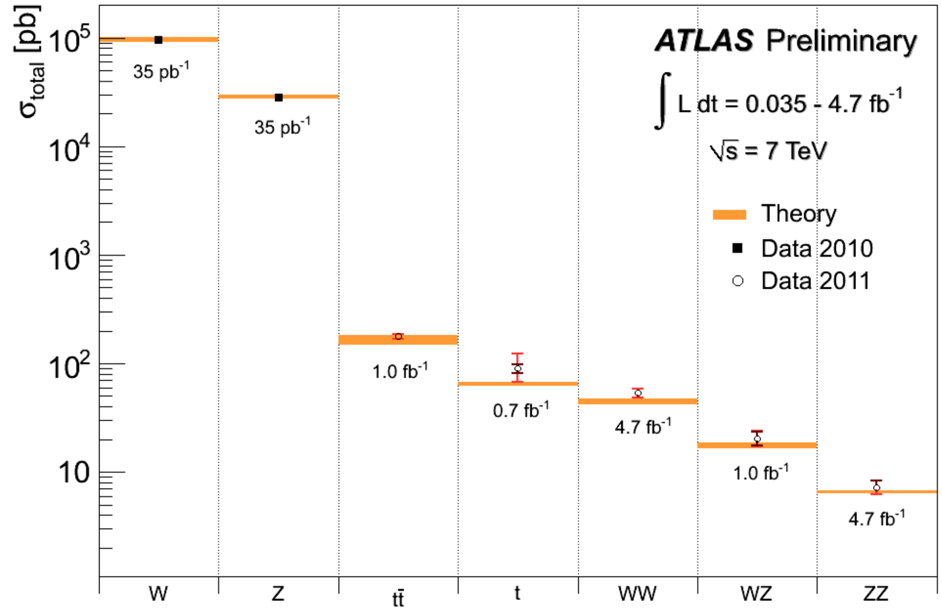
A few Standard Model measurements to gain confidence
A new kinematic regime: looking for resonances
Profumo di SUSY: squark and gluino cascade decays
Boosted objects
Low energy searches
The SM H boson

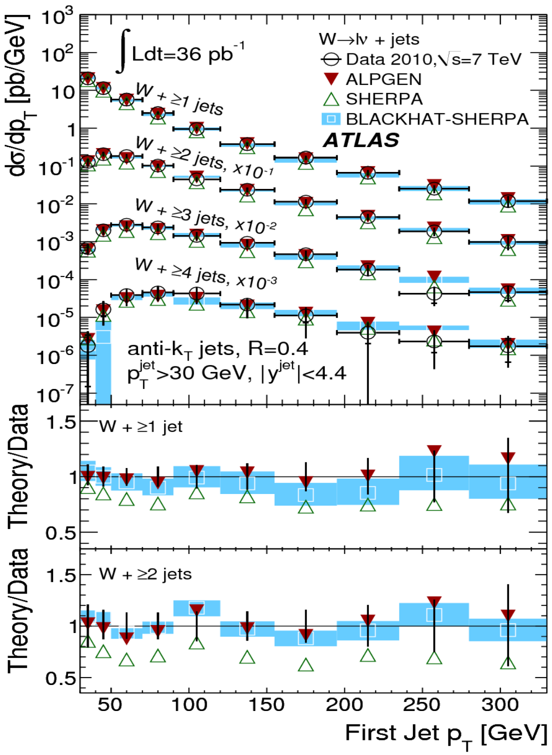


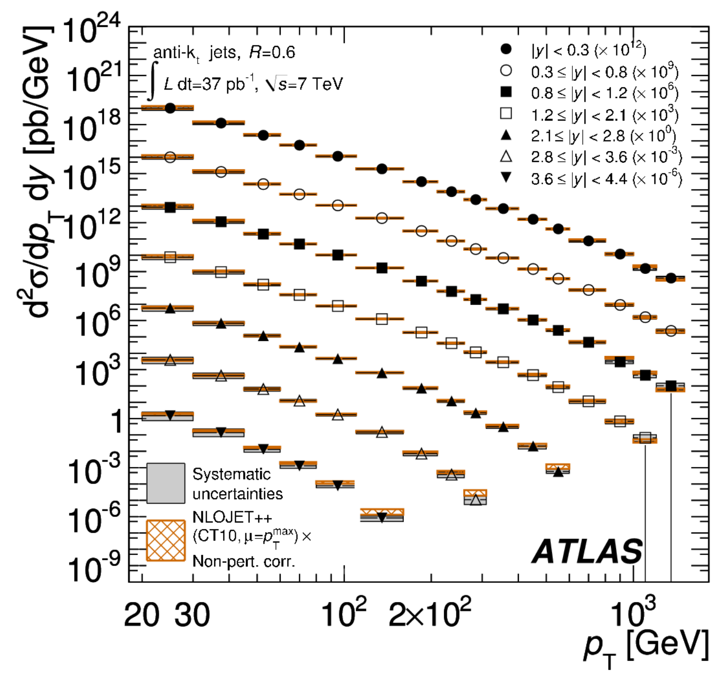
Note that all public results from ATLAS are available at:
https://twiki.cern.ch/twiki/bin/view/AtlasPublic

SM measurements

Fully corrected measurements are a vitally important part of the ATLAS program. The format that ages best.. Early LHC data does not become obsolete...



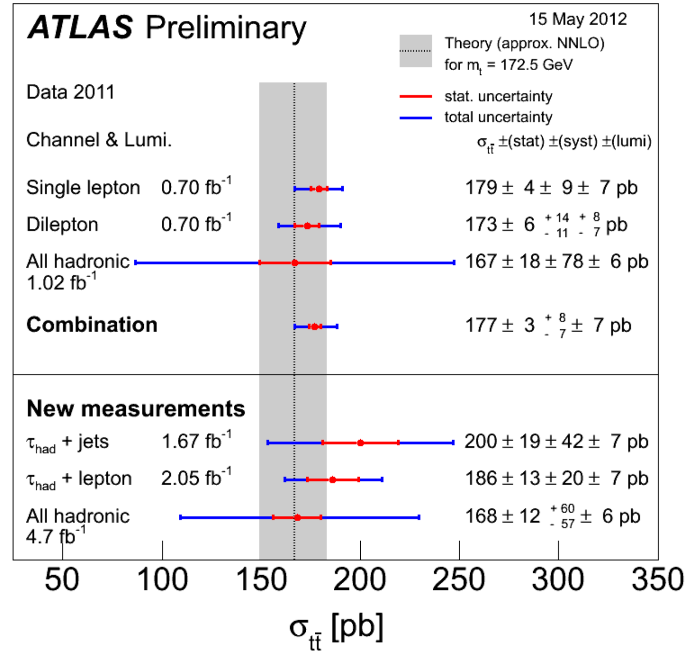




Submutted to Phys. Rev. D
arXiv:1201.1276[hep-ex]

The top quark

Pair production cross section – no suprises



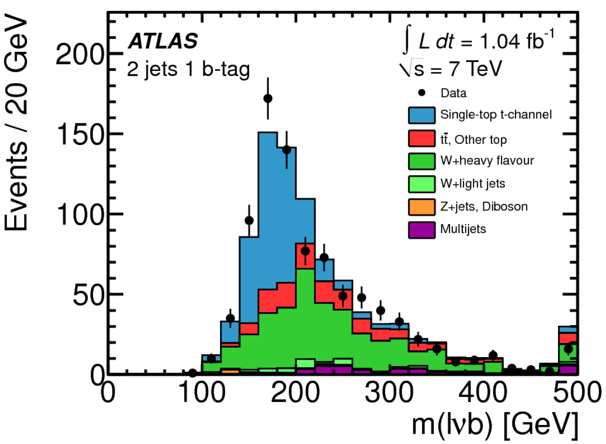
Inclusive charge asymmetry compatible with SM

A_C = -0.018 ± 0.028 (stat.) ± 0.023 (syst.)

m_t = 174.5 ± 0.6 (stat) ± 2.3 (syst) GeV

Spin correlations, W polarization,...

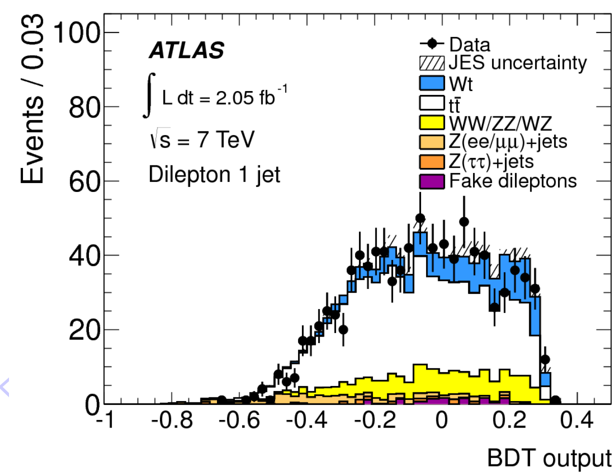
Measurement of the t-channel single top-quark production cross section in pp collisions at √s = 7 T



X-sec = 83±4 (stat.)$^{+20}_{-19}$(syst) pb

Assuming $|V_{tb}| >> |V_{td}|, |V_{ts}|$

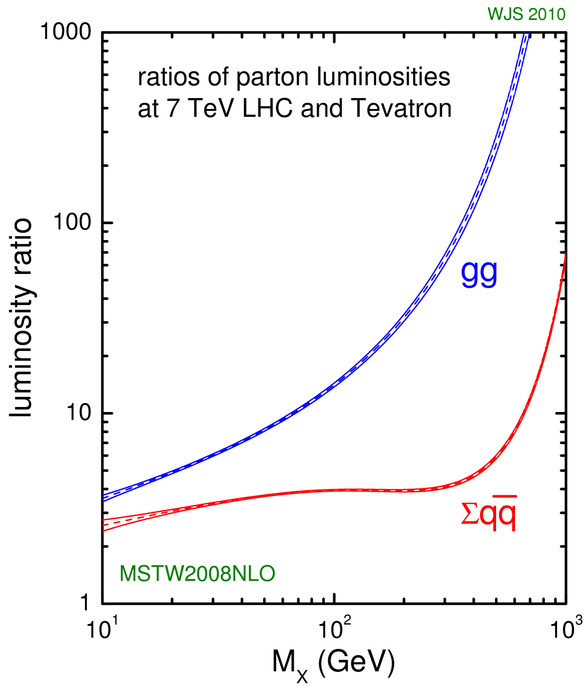
$|V(tb)| = 1.13\ ^{+0.14}_{-0.13}$

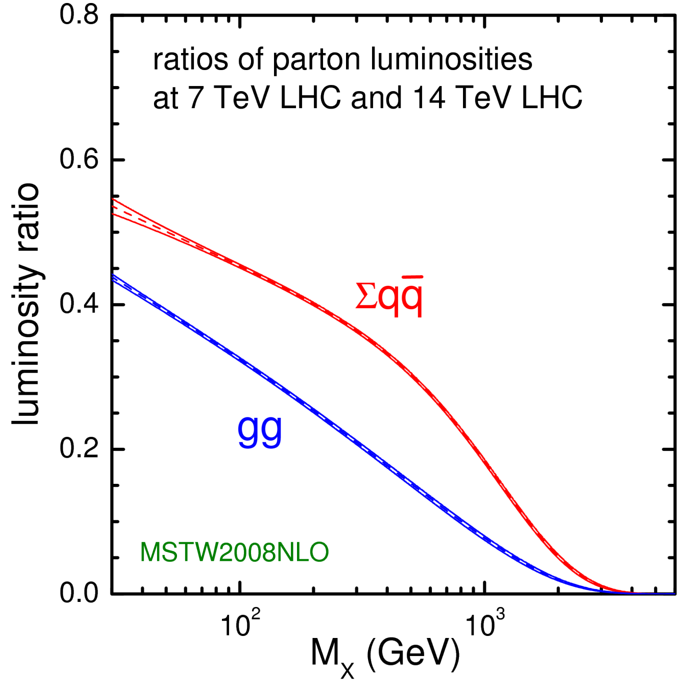


Evidence for the associated production of a W boson and a top quark

Welcome to the TeraScale!

With the LHC we enter a new kinematic regime, even at 7 TeV





Parton luminosity at 1 TeV 2-4 orders of magnitude higher at the 7 TeV LHC than at the Tevatron

Integrated luminosity LHC (5/fb) within a factor 2 of the Tevatron (10/fb) in 2011

For searches, the difference between 0.1 and 1000 events can be discovery!

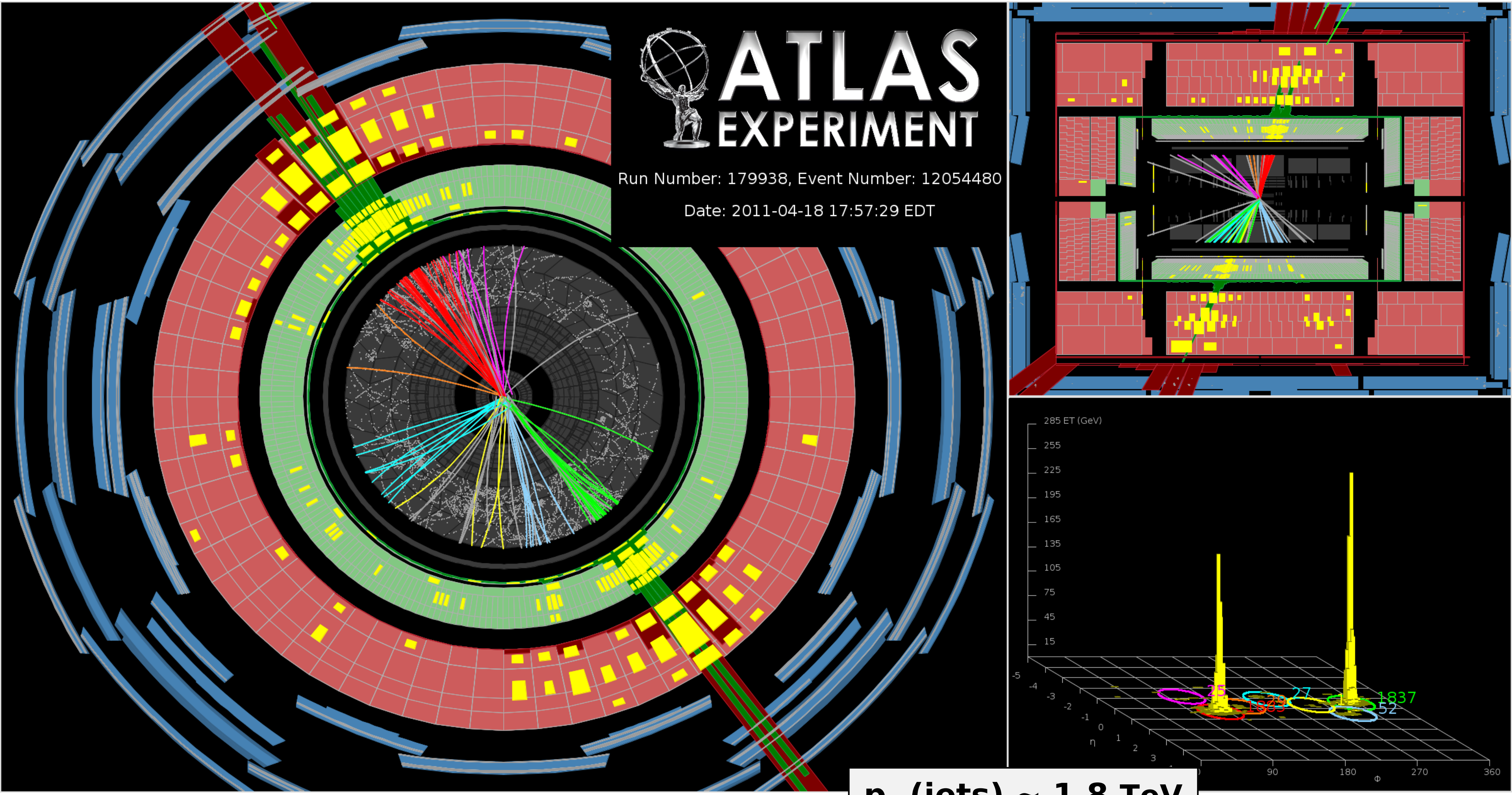
Much more to come: running with peak L~6x10^{33} @ 8 TeV

→ 3/fb collected in 2012

In the longer run: 13 TeV, HiLumi LHC, VLHC

Jets!

One of the most spectacular dijet events recorded by ATLAS: M_{jj} ~ 4 TeV

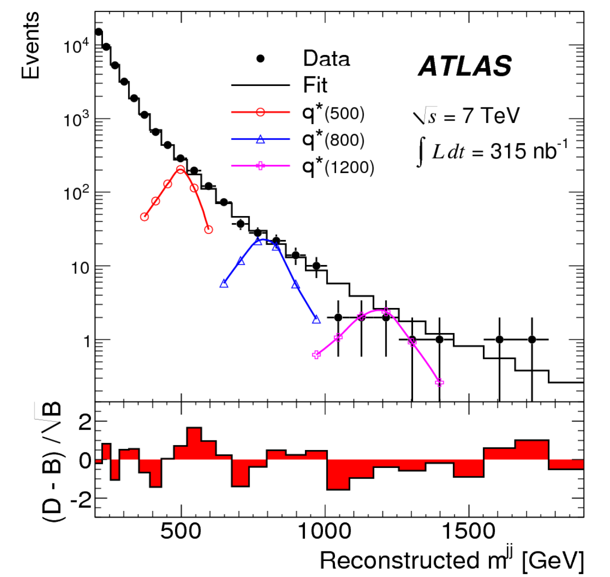


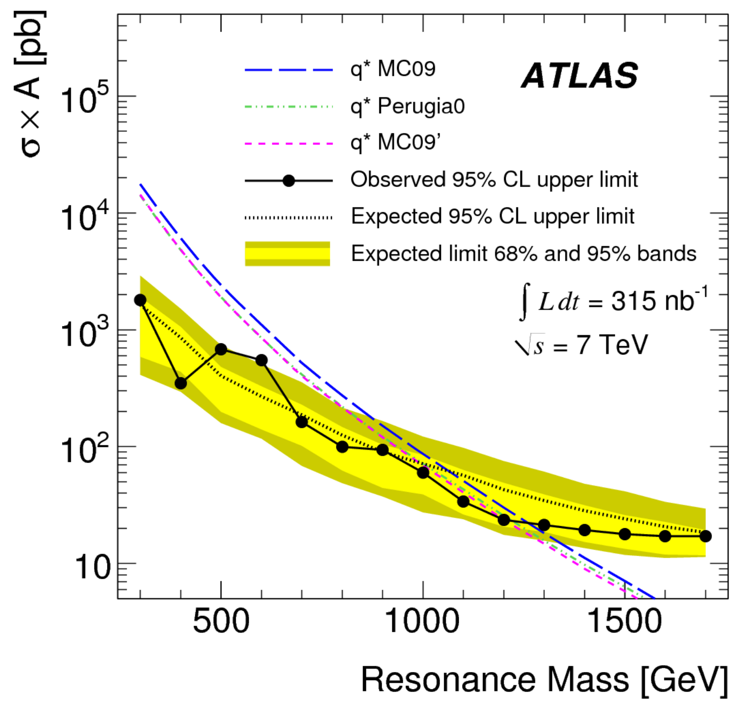
p_T (jets) ~ 1.8 TeV

One of the first ATLAS papers

Accepted on August 30, 2010. The first 7 TeV paper → Phys.Rev.Lett. 105 (2010) 161801

Switch on the machine and hunt for bumps!





With L =315/nb, *"These exclude at the 95% CL the q∗ mass interval 0.30 < mq < 1.26 TeV, extending the reach of previous experiments"*

That's what entering a new kinematic regime can do for you!

One word about benchmark models

Most searches end with a negative result
How do we communicate this result most effectively to the model builder?
How do we compare searches by different experiments?

The absence of a signal is interpreted in terms of some BSM model
→ limits are derived on the mass or rate of some new particle

Ultimately, a matter of consensus. We don't need the model to be particularly well-motivated physically (i.e. sequential Z', excited quark q*)

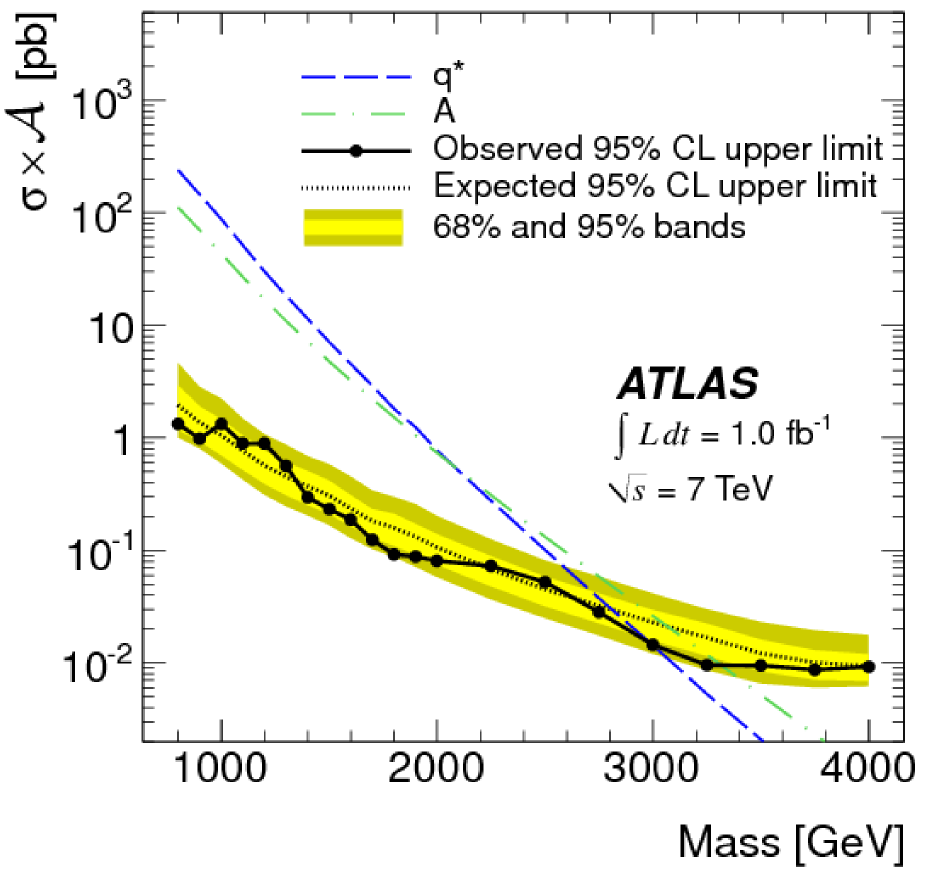
Can often recast (reinterpret the result in terms of some other model)

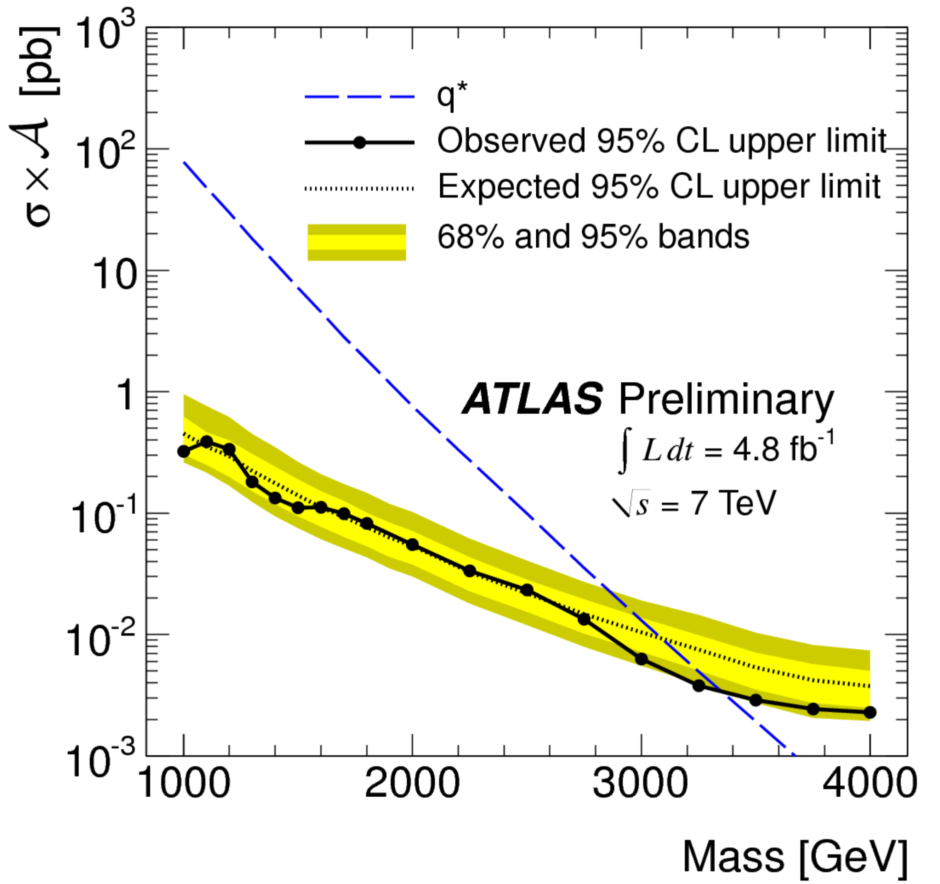
Alternative solutions (each with its own limitations):

- simplified models (we'll see a SUSY example later)
- effective operators (capture global features of BSM family)
- correct the data, report a particle-level cross-section, asymmetry,..

High-lumi follow-up study

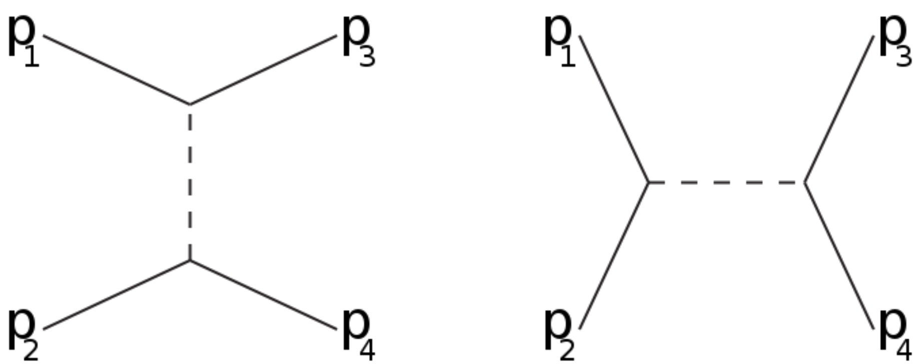
And this is what luminosity can do: follow-up with 1/fb and 5/fb has increased the mass reach for excited quark up to 2.99 TeV and 3.35 TeV (was 1.26 TeV with 315/nb)





Now you understand why people involved in “searches” are always asking for higher center-of-mass energy (even if you still don't know what a q* is)

Angular distributions



The SM predicts the relative amount of s- and t-channel production.
A BSM source of dijet events may upset that mixture.

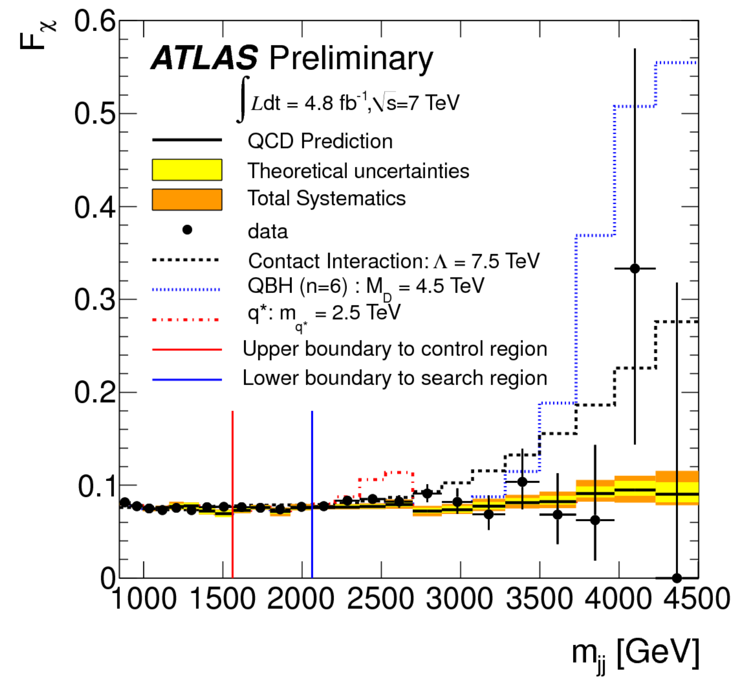
Particularly relevant for non-resonant production.

Another “angle” to look at the same data:

$\chi = e^{(|y1-y2|)}$ $F\chi = N_{central}/N_{total}$

The SM χ distributions are relatively flat compared to those produced by new phenomena...

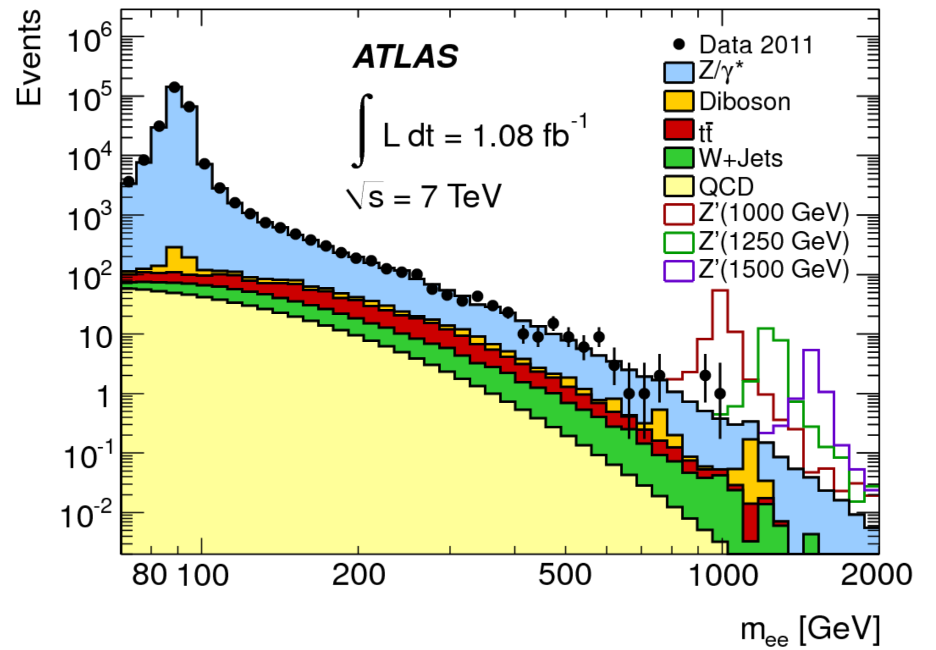
Reach a compositeness scale of 7.8 TeV

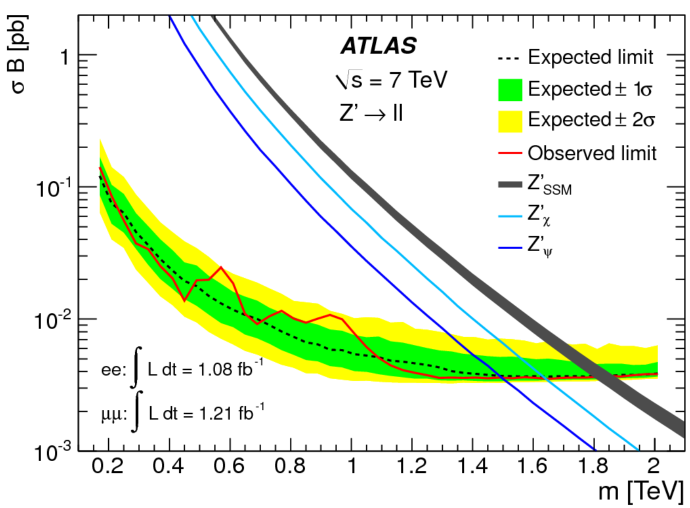


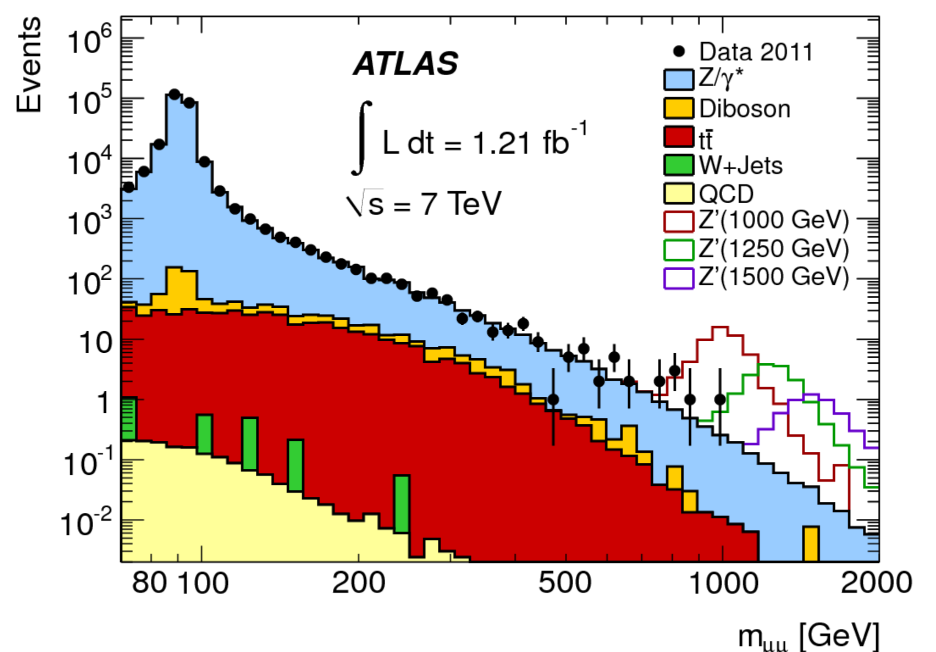
Dilepton resonances

Phys.Rev.Lett. 107 (2011) 27200

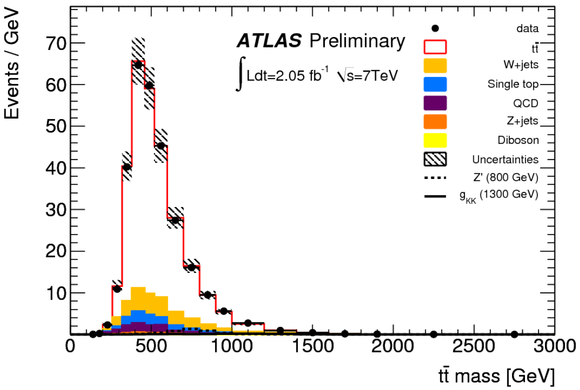
:) Mass resolution!
:/ Production rate @ LHC





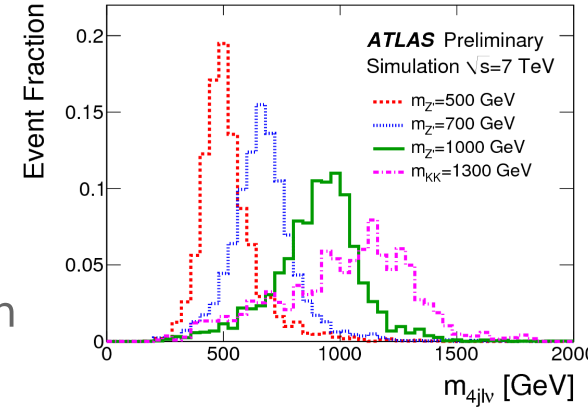


tt resonances

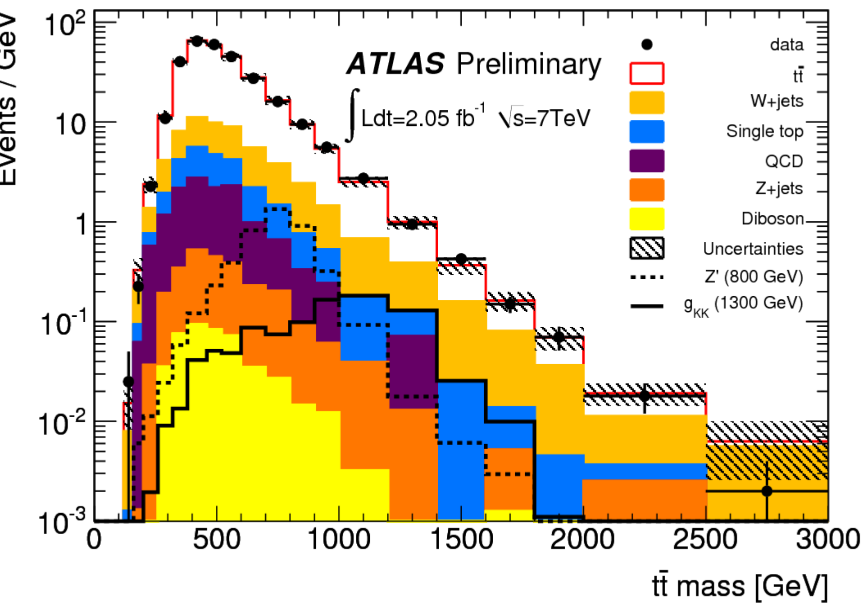


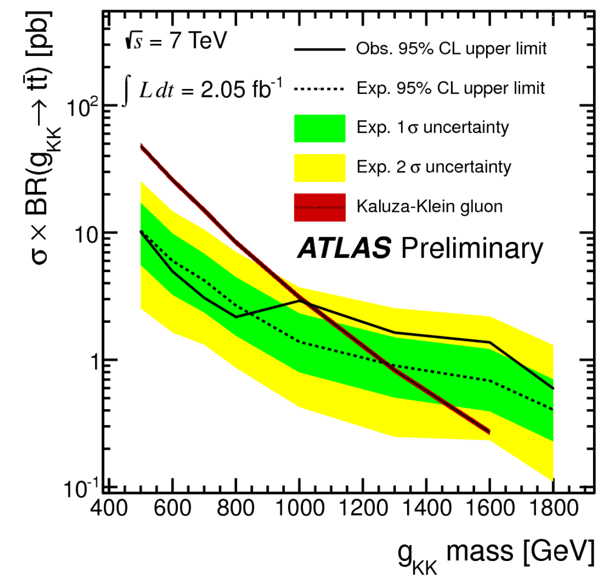
Expect 80% SM population of the Signal Region is due to tt pair production

tt system reconstruction
10% mass resolution



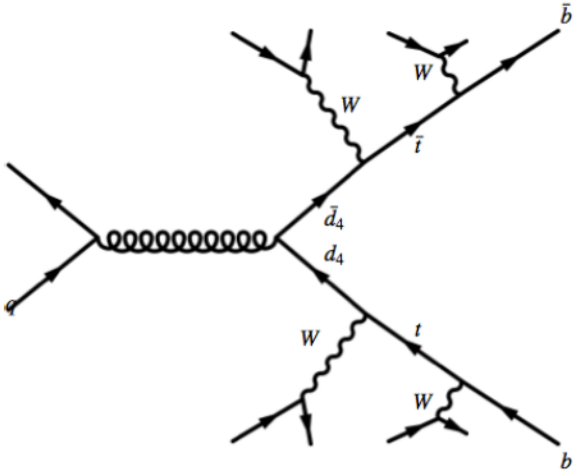
Full Signal Region





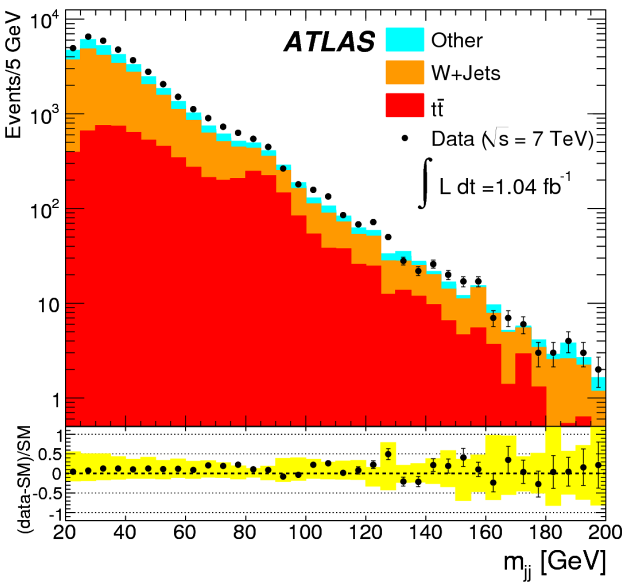
Depending on what you're looking for, the differential) cross-section, the charge asymmetry, same-sign top quark search, tt + missing energy, ... may be more relevant
If you're still here on Saturday, come to the BSM new phenomena discussion

b'b' → W^+tW^-t

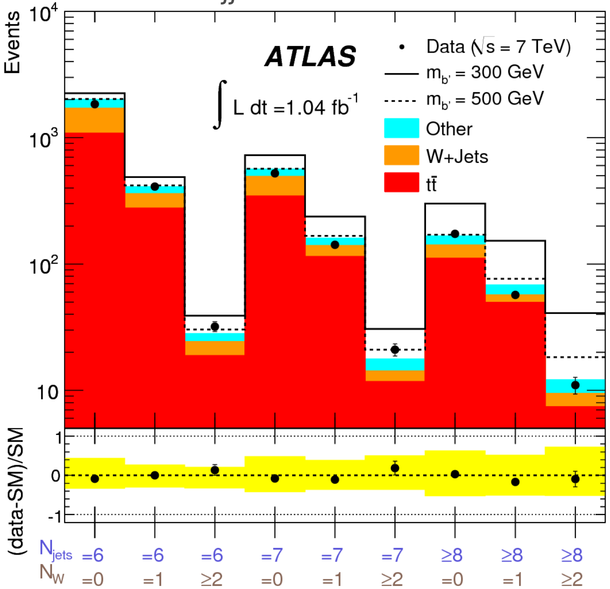


"Boosted objects without substructure"
(ATLAS b' search in arXiv:1202.6540)
Signal: tt pair + 2 boosted W bosons

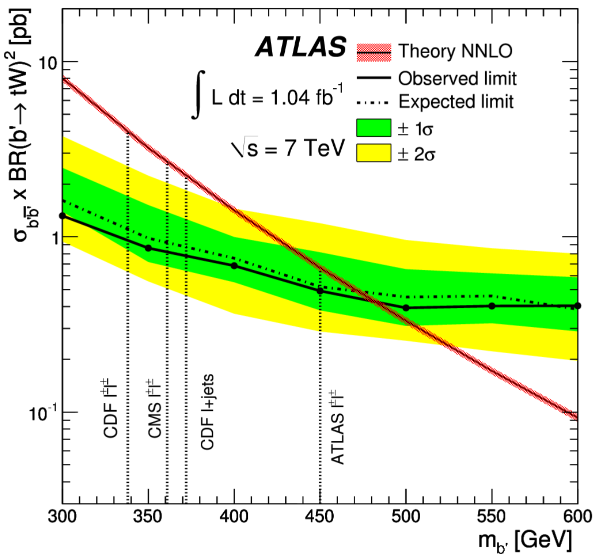
Combine two R=0.4 jets in a ΔR < 1 cone



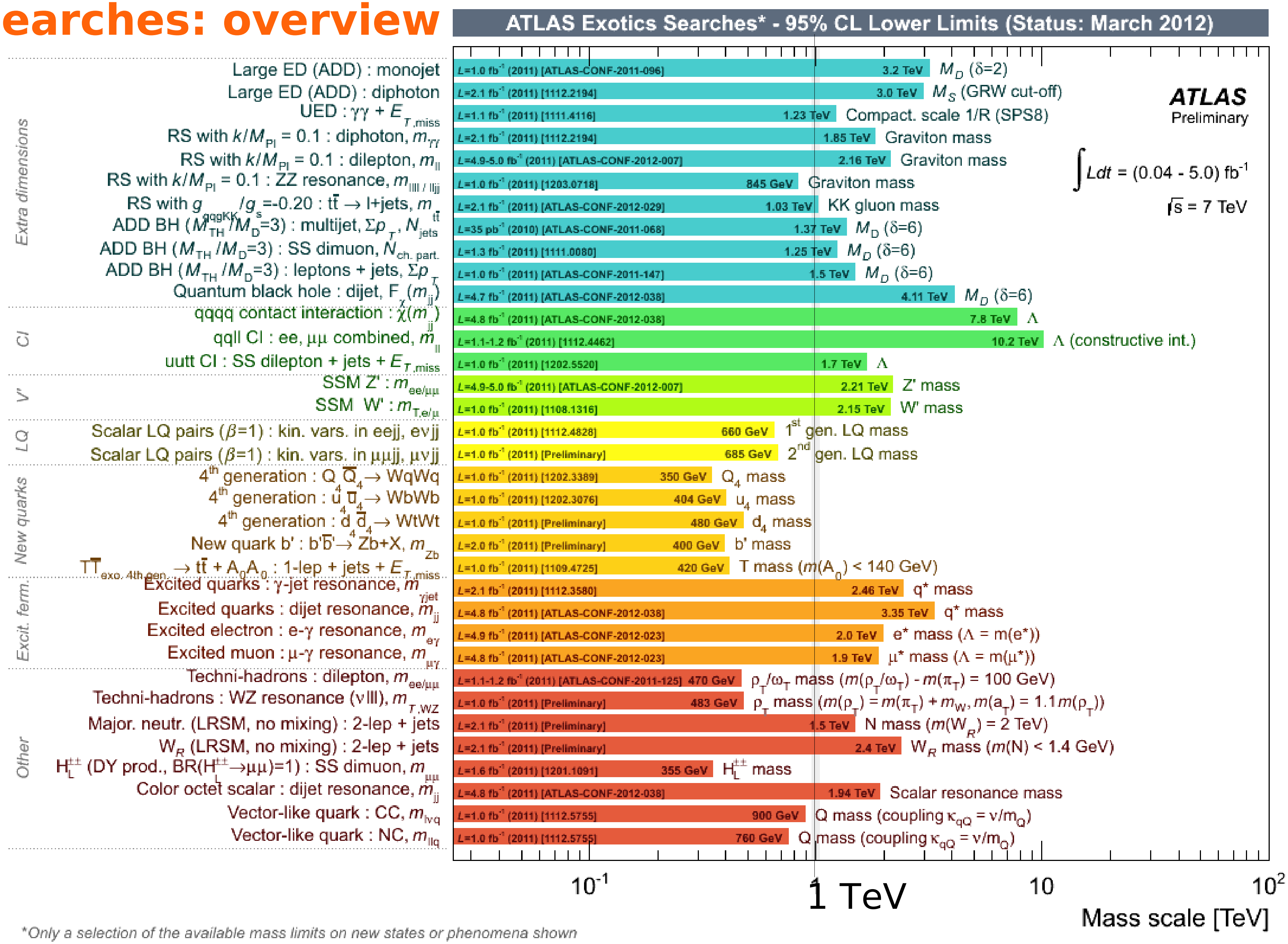
Count the Ws (pairs with $70 < m_{jj} < 100$ GeV



Exclusion at 95 % CL m(b') < 480 GeV



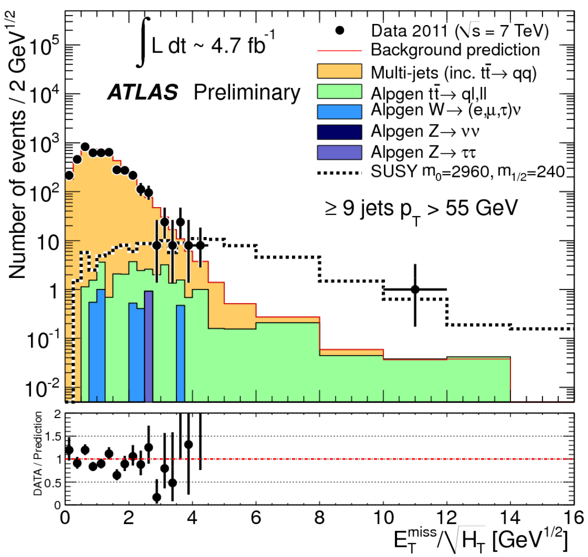
Searches: overview

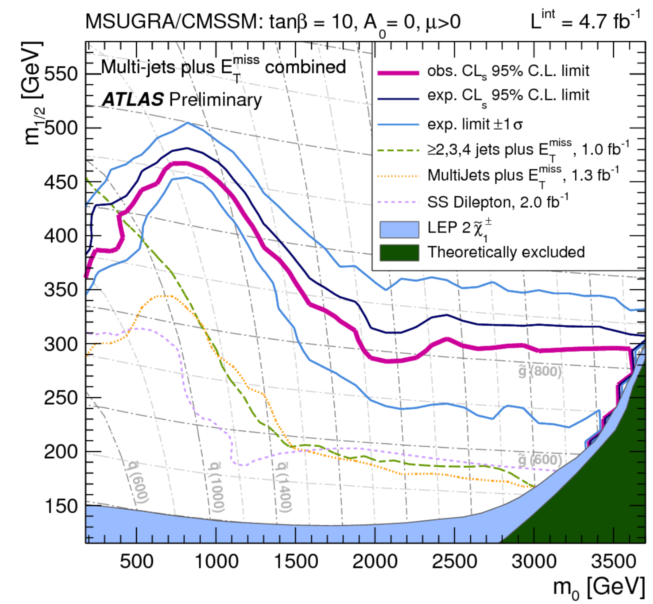


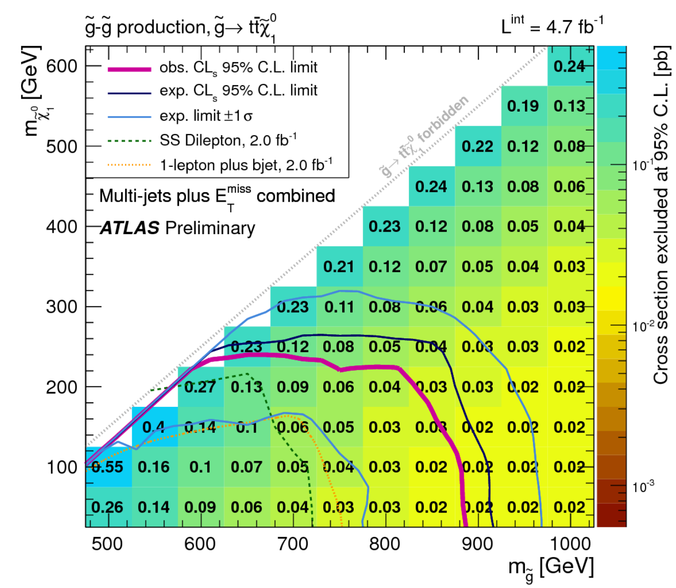
Supersymmetry

Conserve R-parity (SUSY particles produced in pairs, Lightest Stable Particle escapes detection)
Inclusive search, primarily sensitive to abundant squark and gluino production:
- cascade decays to SM particles + LSP
- simple model pp → gg → ttχttχ

Derive a data-driven SM prediction based on data in a (signal-free) control region
Compare the template to data in regions with some distinct signature (missing energy, large multiplicity)



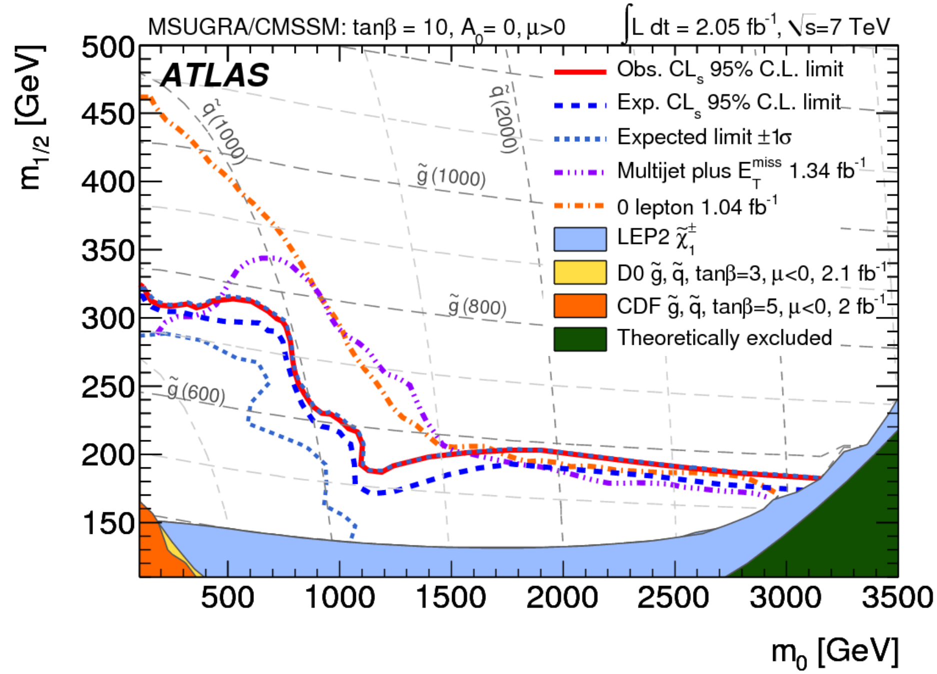


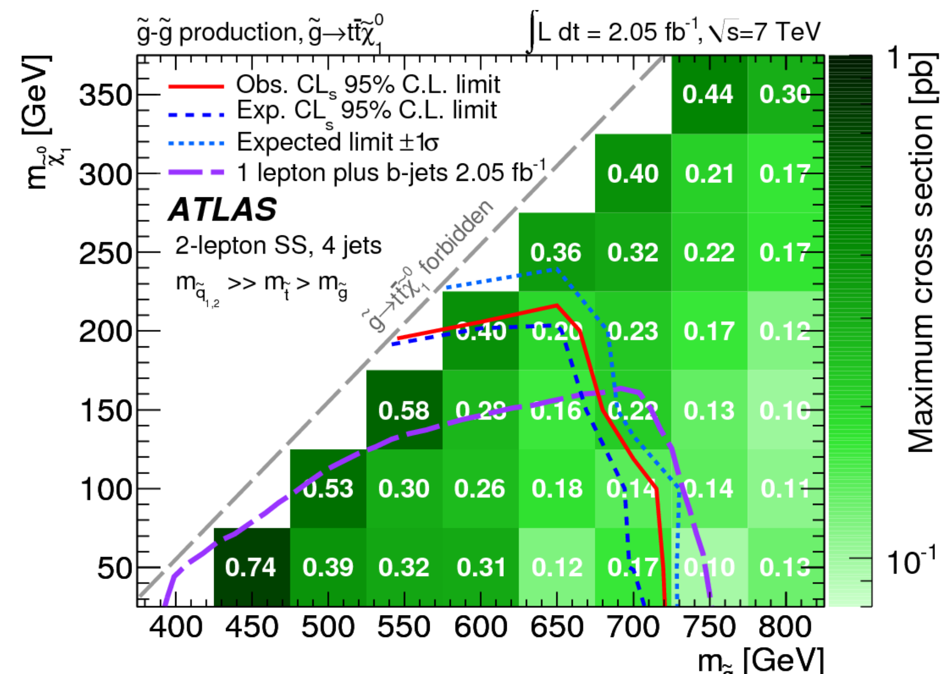


Supersymmetry

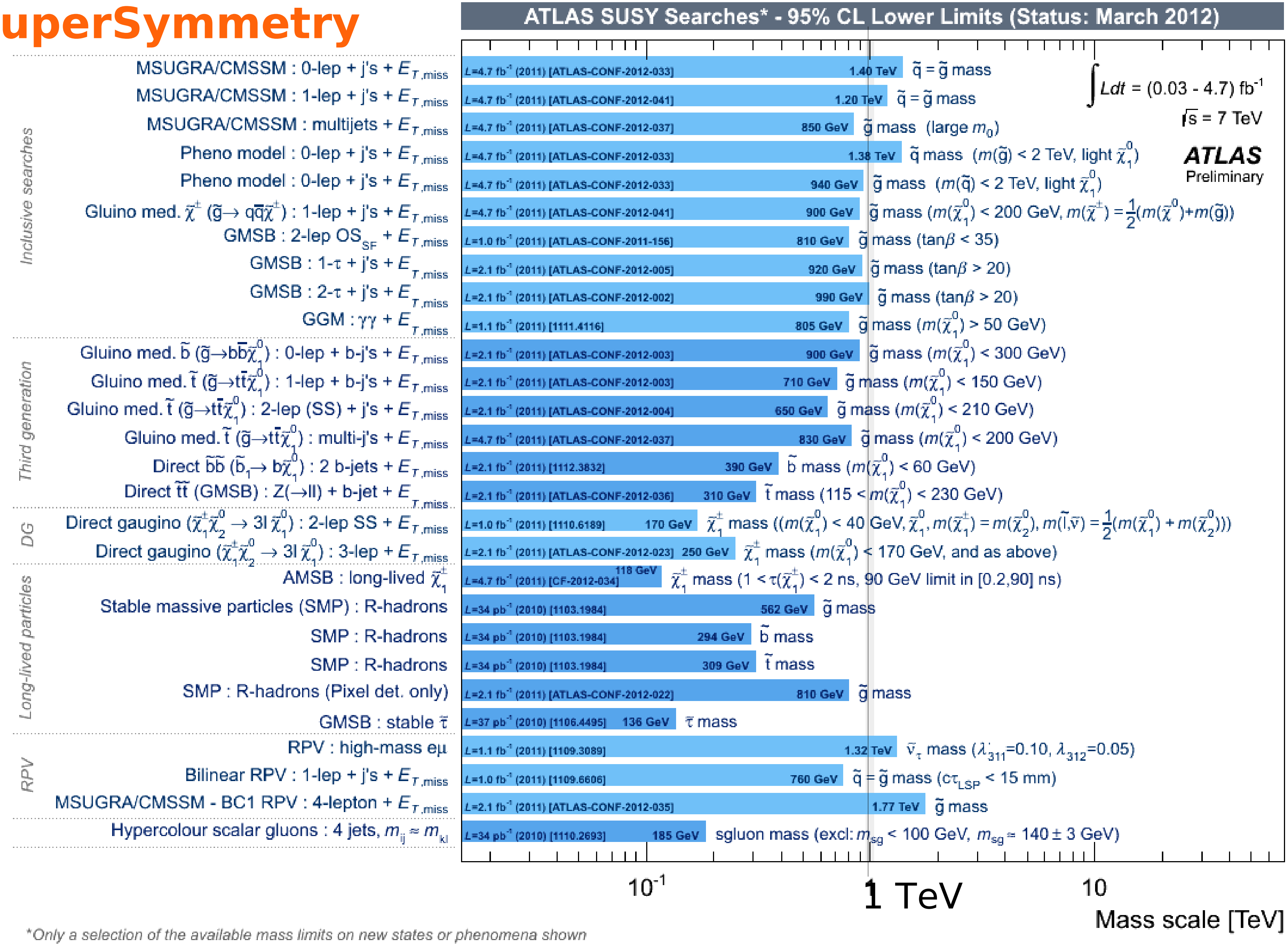
Specific analyses for the third generation (recent ATLAS papers use bottom, τ-lepton and top quark signatures)

Much more distinctive signature: same-sign lepton + 4 jets





SuperSymmetry



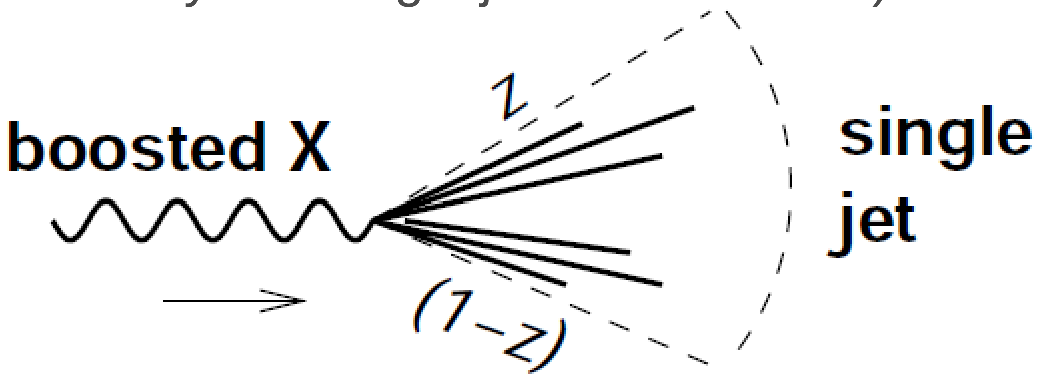
Boosting BSM sensitivity

Let's define "boosted object" by comparing the standard approach (reconstruct components and combine) **to Mike Seymour's alternative** (find composite object and decompose).

Rules of thumb for maximum jet radius parameter for 2-body decay:

$R < 2m/p_T$ (always resolve two jets)

$R > 3m/p_T$ (capture full decay in a single jet 75% of cases)



W boson at rest → use resolved approach

p_T ~ 240 GeV → coexisting algorithms,

can resolve with R=0.4, or contain in R=1

p_T ~ 400 GeV → boosted regime

cannot always resolve with R=0.4

Boosted top quarks

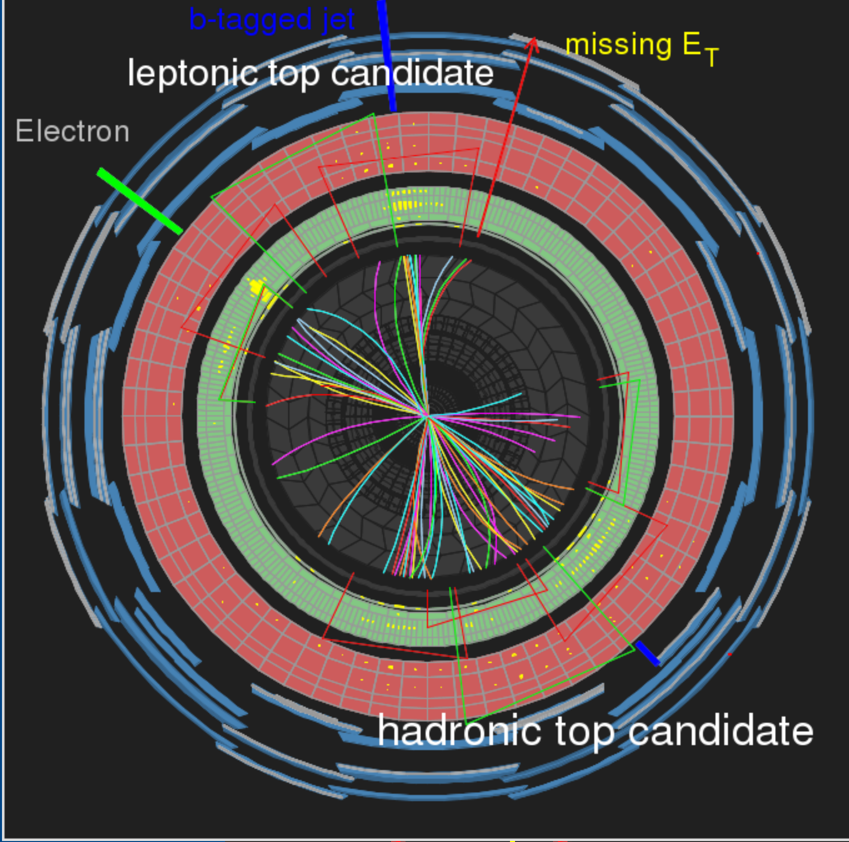
2010 data: the first five events of what will become an excellent control sample

When reclustered with R = 1.0 three jets merge into a single “fat” jet with:

m_j = 197 GeV (expected: m_t)
sqrt(d_{12}) = 110 GeV (expected ~m_W)
sqrt(d_{23}) = 40 GeV (expected …)

Matching small and large jets we can transfer the small uncertainties of the well-known jets to less well-know ones

Measurement of Jet Mass and Substructure for Inclusive Jets in √s = 7 TeV pp Collisions with the ATLAS Experiment, ATLAS-CONF-2011-073

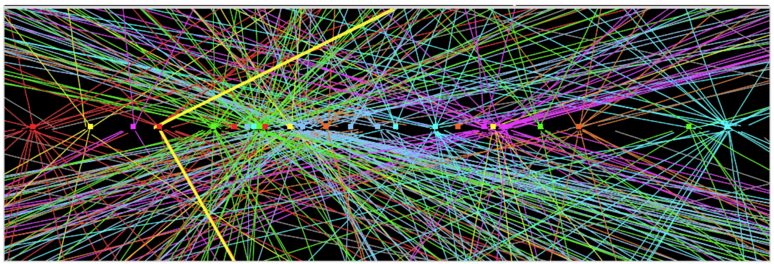


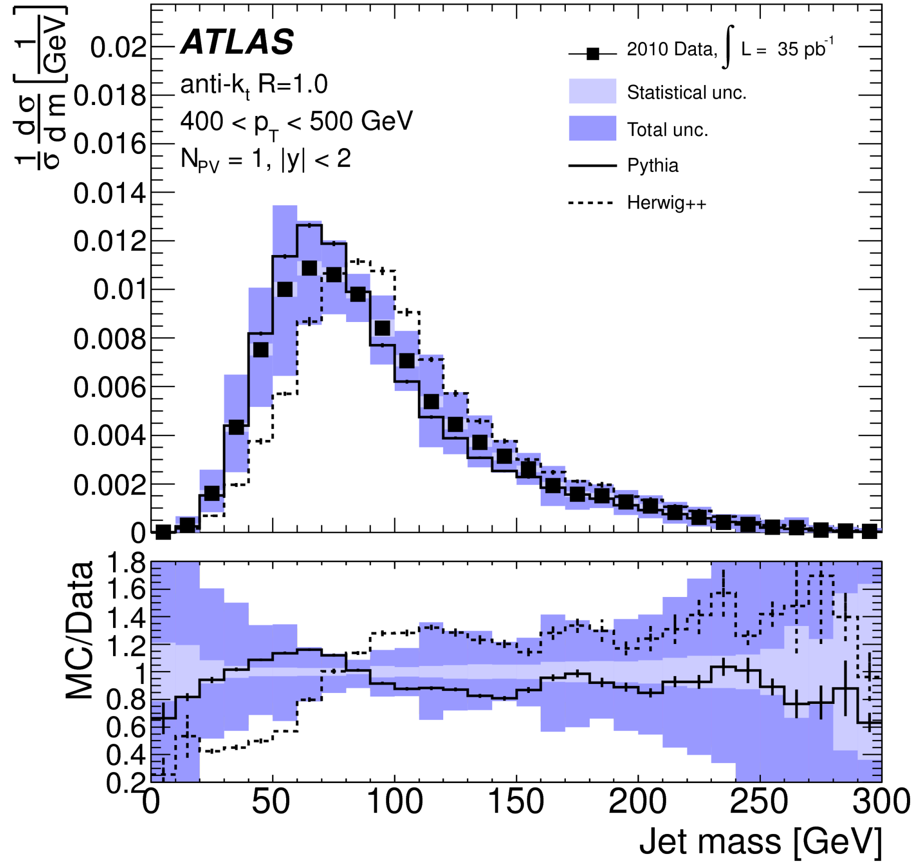
Resolved for R=0.4, Boosted object for R=1

Jet substructure

arXiv:1203.4606 [hep-ex]

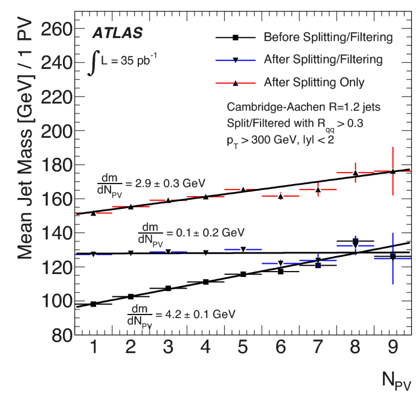
Agreement SM - data
- Parton Shower model is adequate
- Detector response is under control
- Underlying event OK

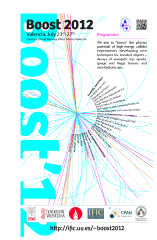




2010: few events/crossing
(20% has a single primary vertex)
2011: average 12 events/crossing
(50 ns operation; machine beyond design)
2012: average up to ~25 events/crossing
(8 TeV, squeezed beams: β*=0.6m)

Jet grooming increases pile-up resilience



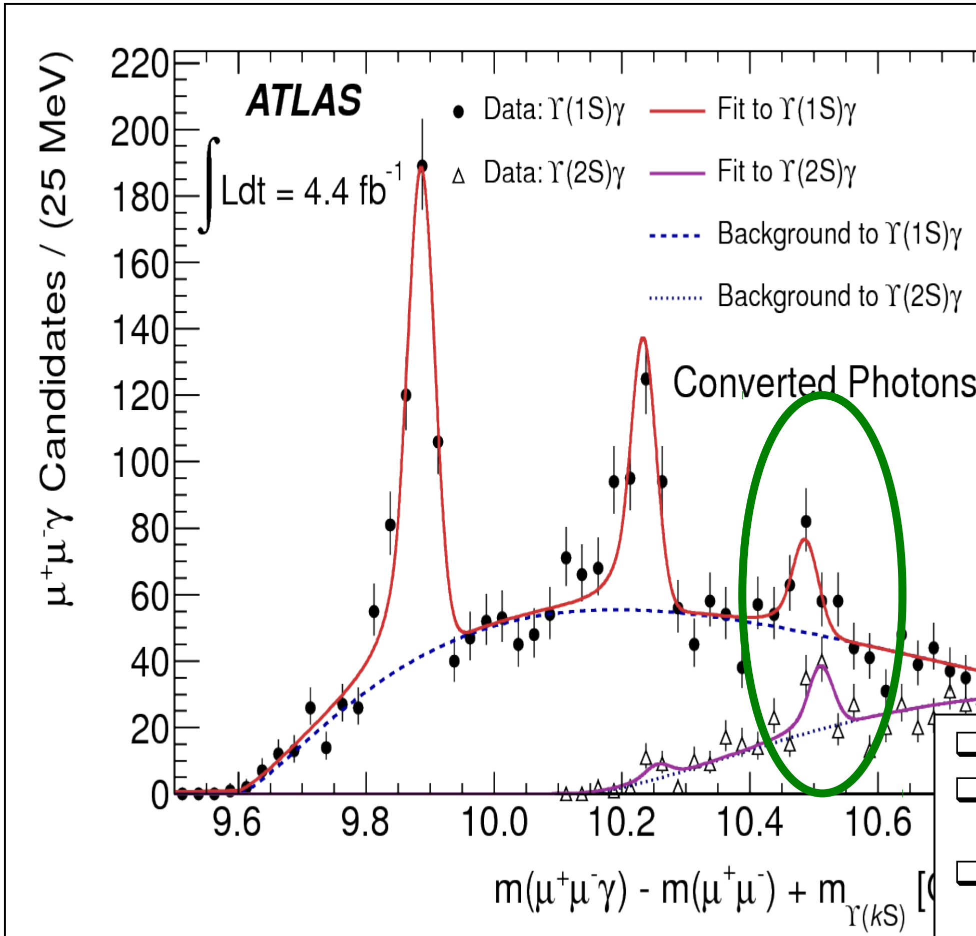


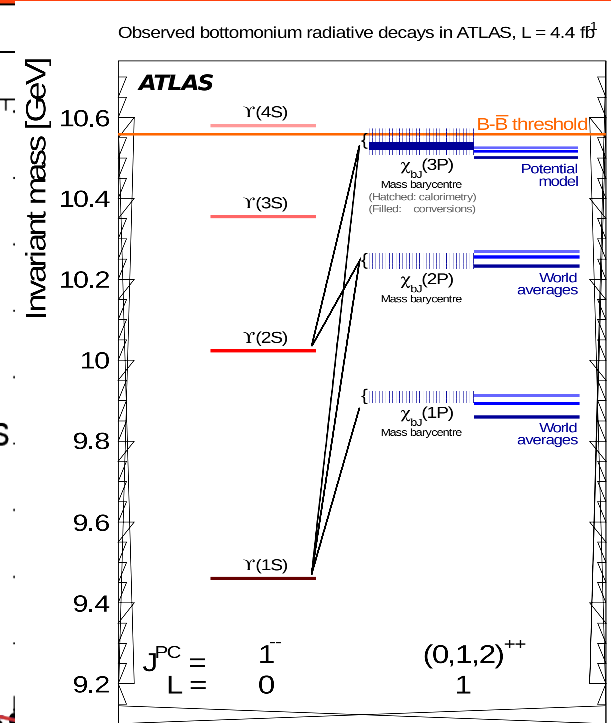
Come to Valencia this summer

marcel.vos@ific.uv.es

New particles at the LHC!

$X_b(3P) \rightarrow Y(1s,2s)\ \gamma$ | $m\ [\chi_b(3P)] = 10.530 \pm 0.005\ (stat) \pm 0.009\ (syst)$ GeV





- **$\chi_b(nP) \rightarrow Y(1s,2s)\ \gamma \rightarrow \mu\mu\ \gamma$**
- **$X_b(1P)$ m= 9.9 GeV and $X_b(2P)$ m= 10.2 GeV states clearly visible**
- **New structure at 10.5 GeV $\rightarrow X_b(3P)$**
- **Confirmed with Y(2s) data and with un-converted photons**
- **Significance > 6 σ**
- **As theoretically predicted**

Confirmed at TeVatron (see Jesus Vizan's talk)
Also, $B_s \rightarrow \mu\mu$

The H boson

A word of caution

In particle physics, the Higgs mechanism is the process that gives mass to elementary particles. The simplest implementation of the mechanism adds an extra Higgs field to the gauge theory.

In the Standard Model, the phrase "Higgs mechanism" refers specifically to the generation of masses for the $W^{\pm}$, and Z weak gauge bosons through electroweak symmetry breaking. The SM yields definite predictions for everything but the mass of the H boson.

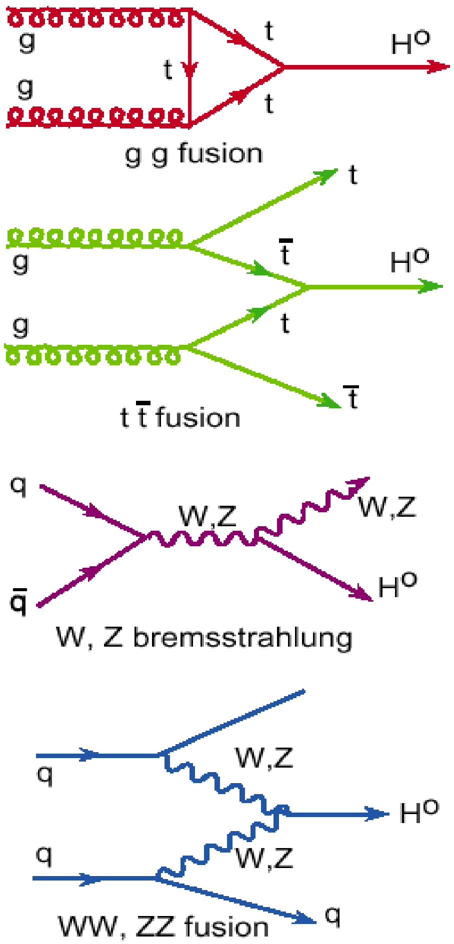
Observation of a resonance with Higgs-like properties

$\neq$

discovery of the SM Higgs boson

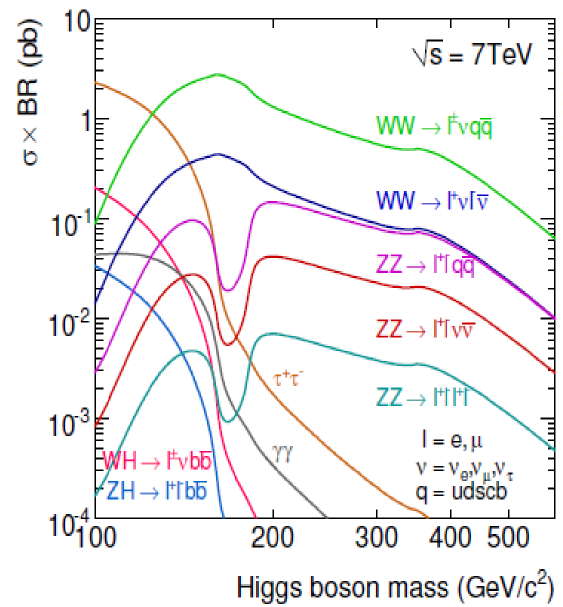
Many BSM proposals have their “Higgs sector”, which may be experimentally distinguishable from the SM Higgs with more data at the LHC (or with a Higgs factory)

The mother of all searches: the H boson

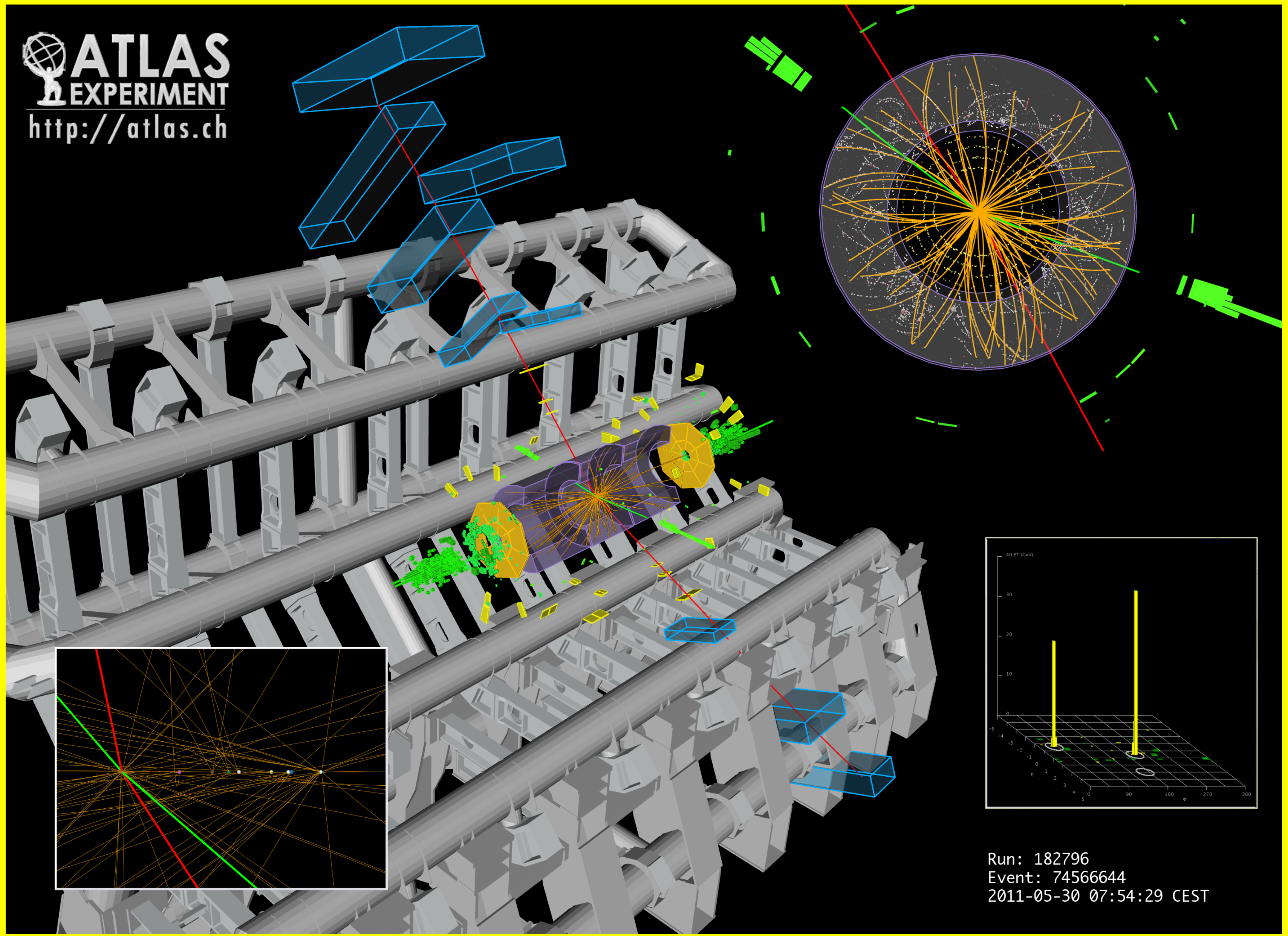


Many production processes, even more decay channels

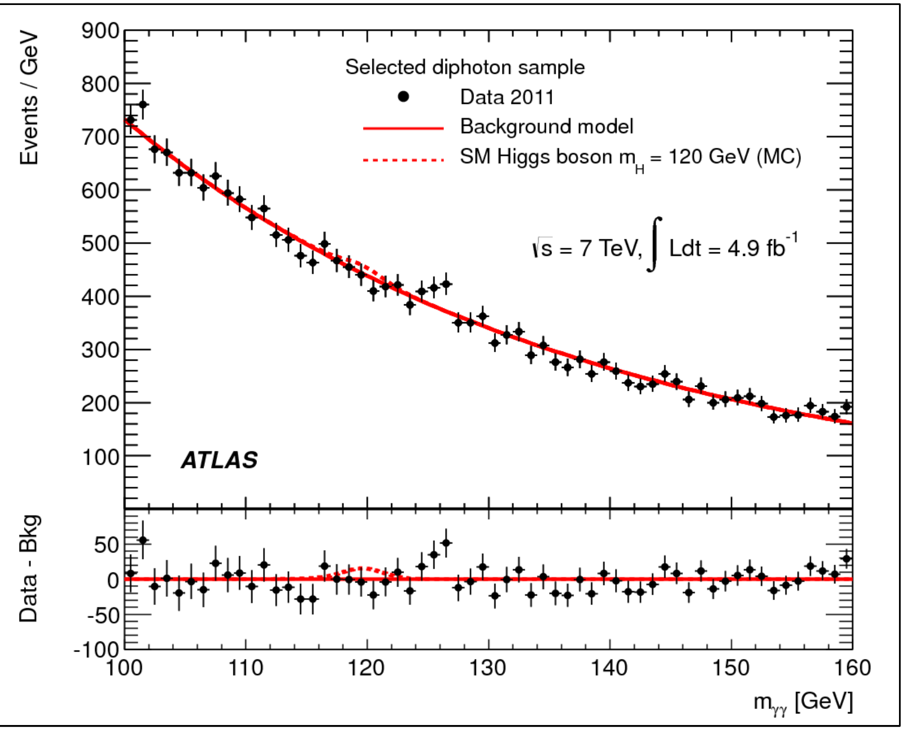
SM H boson production cross sections times observable decay branching ratios at 7 TeV



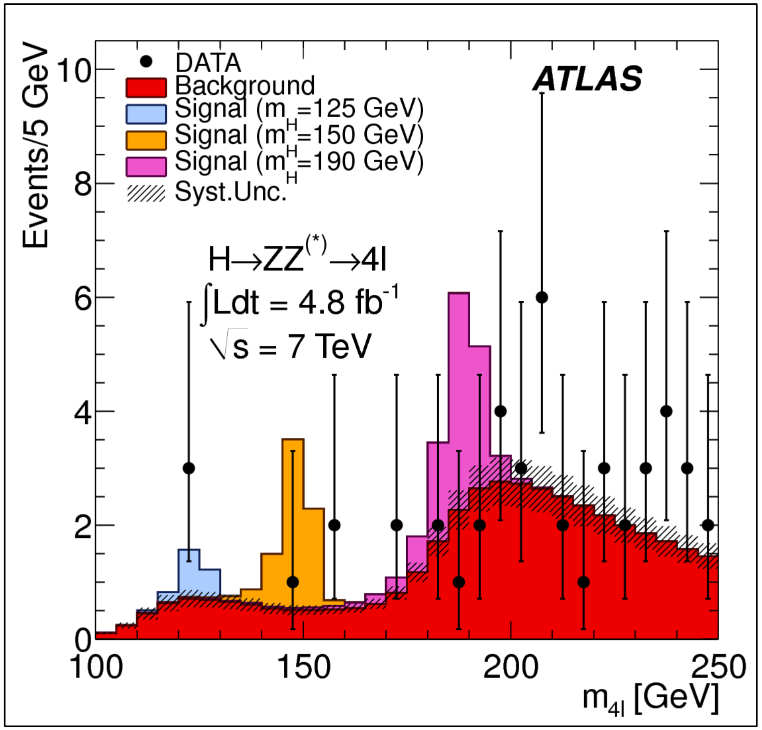
Higgs!


ATLAS
EXPERIMENT
http://atlas.ch
Run: 182796
Event: 74566644
2011-05-30 07:54:29 CEST

High resolution channels: H → γγ and H → ZZ(*) → llll

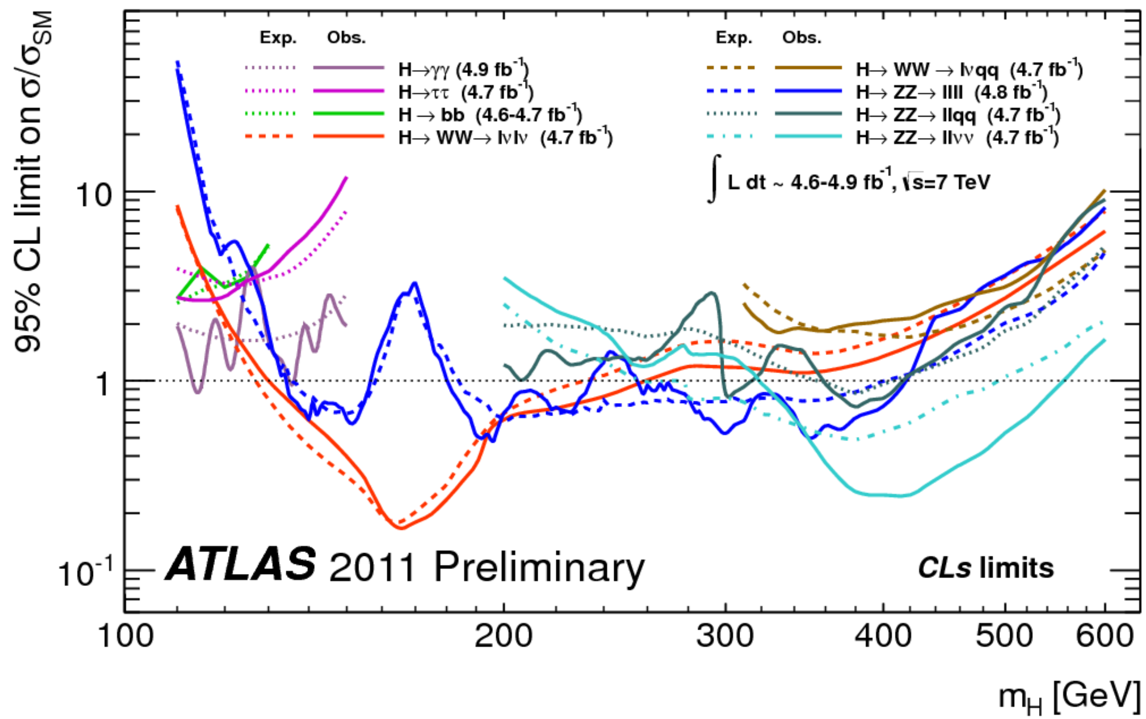


H → γγ:
for m_H ~ 125 GeV, ~70 signal events expected after all cuts, and ~ 3000 background events in signal mass window: S/B ~ 0.02



H → 4l:
in the region mH < 141 GeV (not excluded at 99% CL by ATLAS+CMS combination) 3 events are observed: two 2e2μ events (m=123.6 GeV, m=124.3 GeV) and one 4μ event (m=124.6 GeV)

All channels, all (2011) data, ATLAS-CONF-2012-019

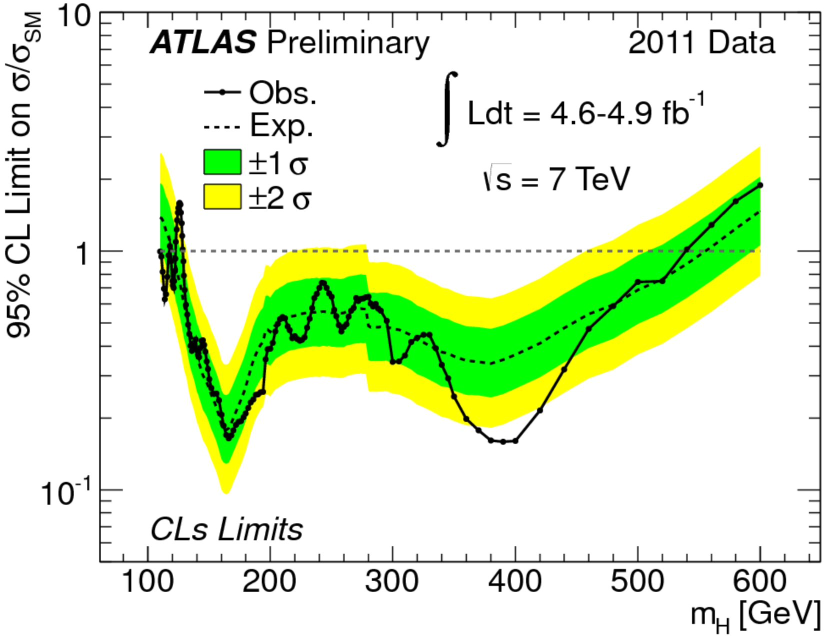


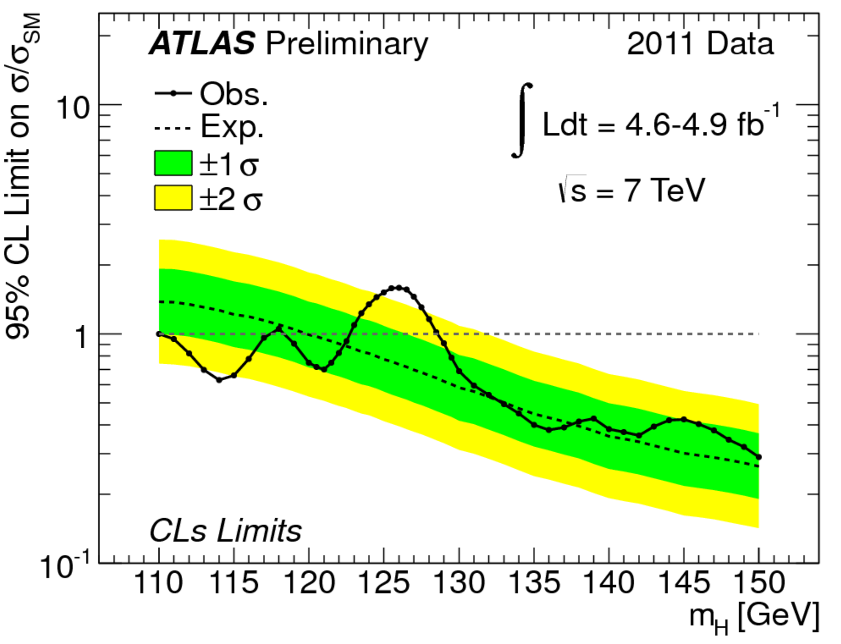
The **ratio of the limit on the rate and the SM cross-section times branching fraction** is plotted
(where the line falls below 1 the SM H boson is excluded)

Expected limits: Estimate the sensitivity of the analysis, from MC without H boson
(if expected limit >> 1, poor sensitivity for SM H boson)
(if observed limit ~ expected limit, data are compatible with no H boson)

Observed limits: the 95% CL limit on the rate from data
(an excess of events causes the the observed limit to be weaker than the expected limit)
(channels with good mass resolution yield sharp localized deviation)
("counting" channels yield a mismatch over a broad mass range)

12 channels, full 2011 data, ATLAS-CONF-2012-019





These figures come with a manual

Expected 95% CL region if no signal: 120 – 555 GeV

Excluded at 95% CL

- $110 < m_H < 117.5$ GeV
- $118.5 < m_H < 122.5$ GeV
- $129 < m_H < 539$ GeV

Interpretation of the excess at 125 GeV

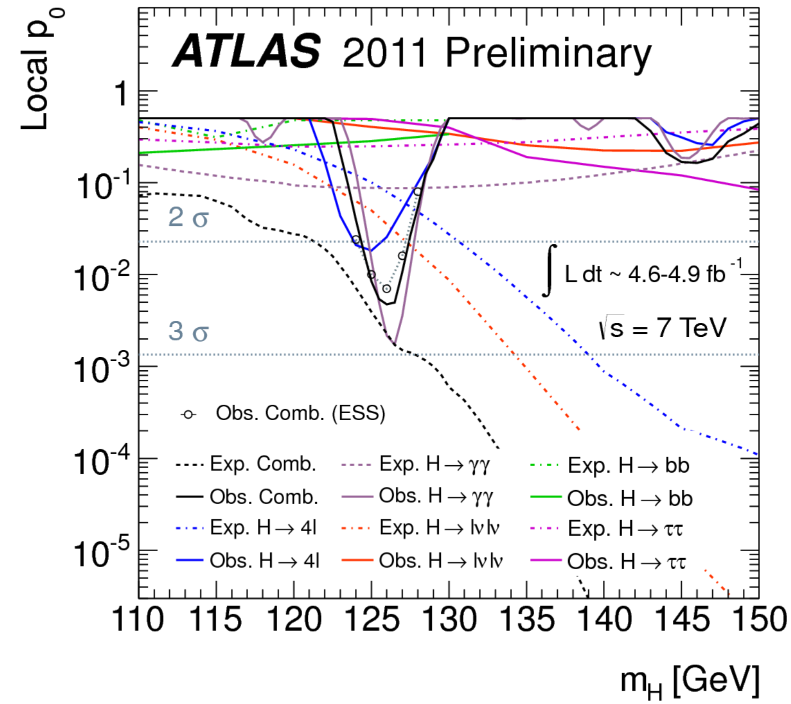
P-value

P_0-value = local probability for a background-only experiment to be more signal-like than the observation.

Solid = observed p_0

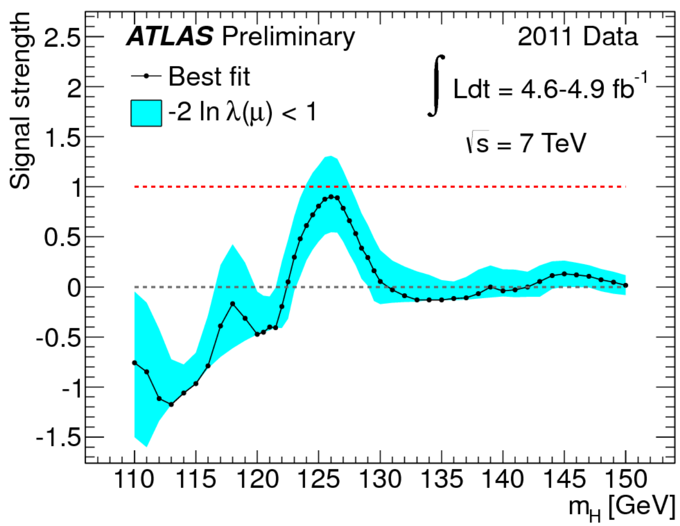
Dashed = median expected value for the hypothesis of a SM Higgs boson signal at that mass.

The global probability for the background to produce such a fluctuation anywhere in the explored Higgs boson mass range 110-600 GeV is estimated to be ~1.4% or, equivalently 2.2 sigma.



Signal strength

μ = best-fit signal strength as a function of the m_H hypothesis.



Summary

ATLAS has published well over 100 physics papers.

Standard Model measurements confirm the SM works for 7 TeV pp collisions

ATLAS has explored an enormous range of potential BSM signatures. Negative result so far extend the constraints on proposed extensions of the Standard Model to a previously uncharged region.

Stay tuned; new results on the Standard Model Higgs boson search soon

8 TeV run well underway. Over 2/fb collected. Adding 100/pb/day on good days. 5/fb by ICHEP, 15/fb in 2012. Cross-sections increase by 25-30% for Higgs production, more for massive objects