ATLAS highlights

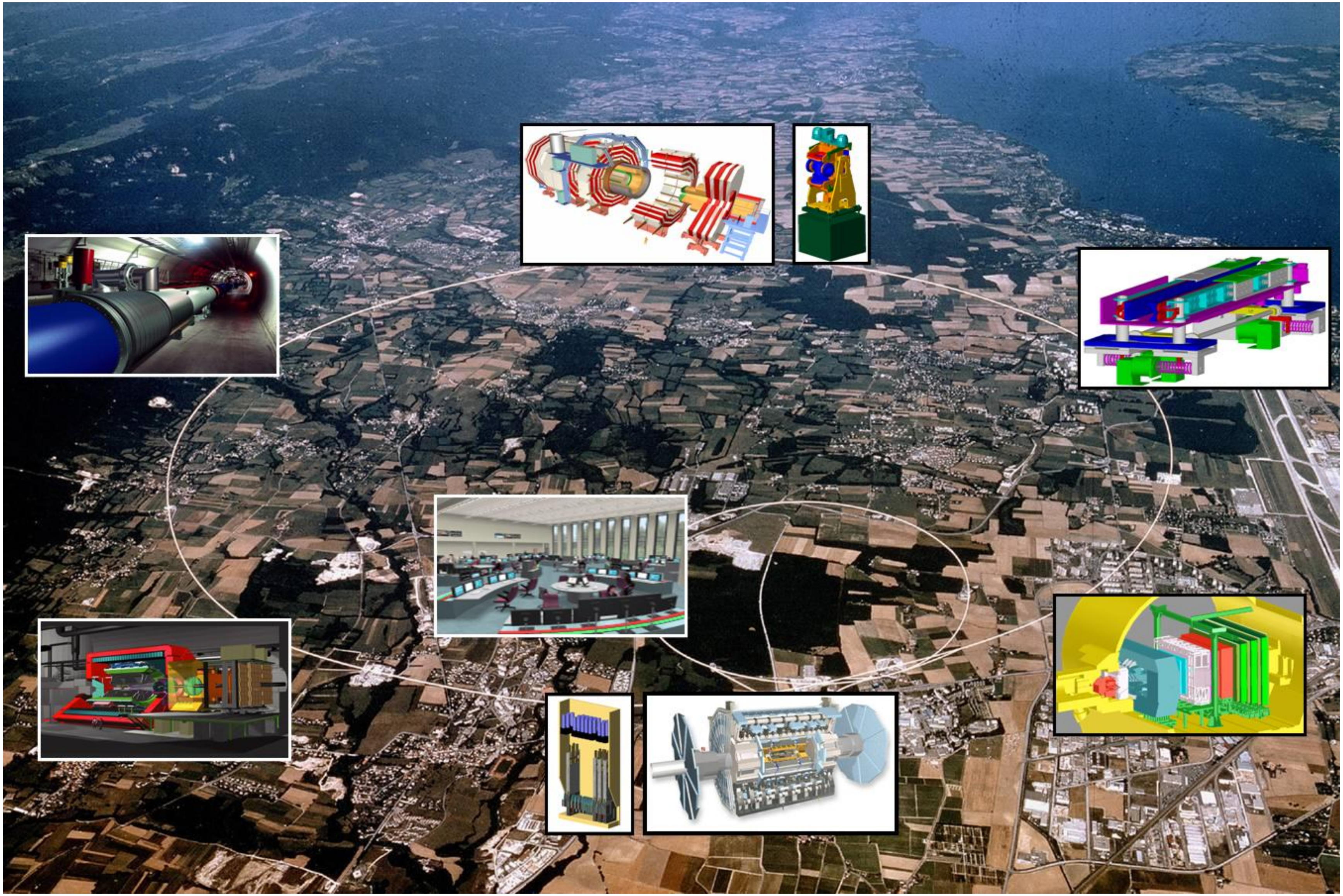
P. Wells, Corfu 2012

ATLAS highlights

The LHC program

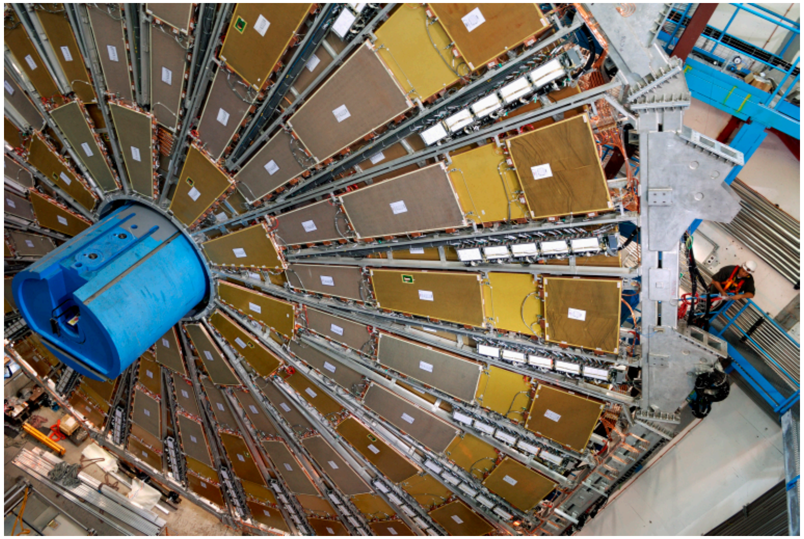
- Re-establish the Standard Model, validate it at high energy: soft and hard QCD, electroweak (di)boson production, top quark production and properties.
- Find or exclude a Higgs Boson (see L. Fayard)
    - “Are we there yet?”
- Heavy Flavour physics – matter-antimatter asymmetry (see C. Tsarouchas)
- Direct and indirect searches for physics beyond the Standard Model

The LHC



ATLAS – A general purpose detector

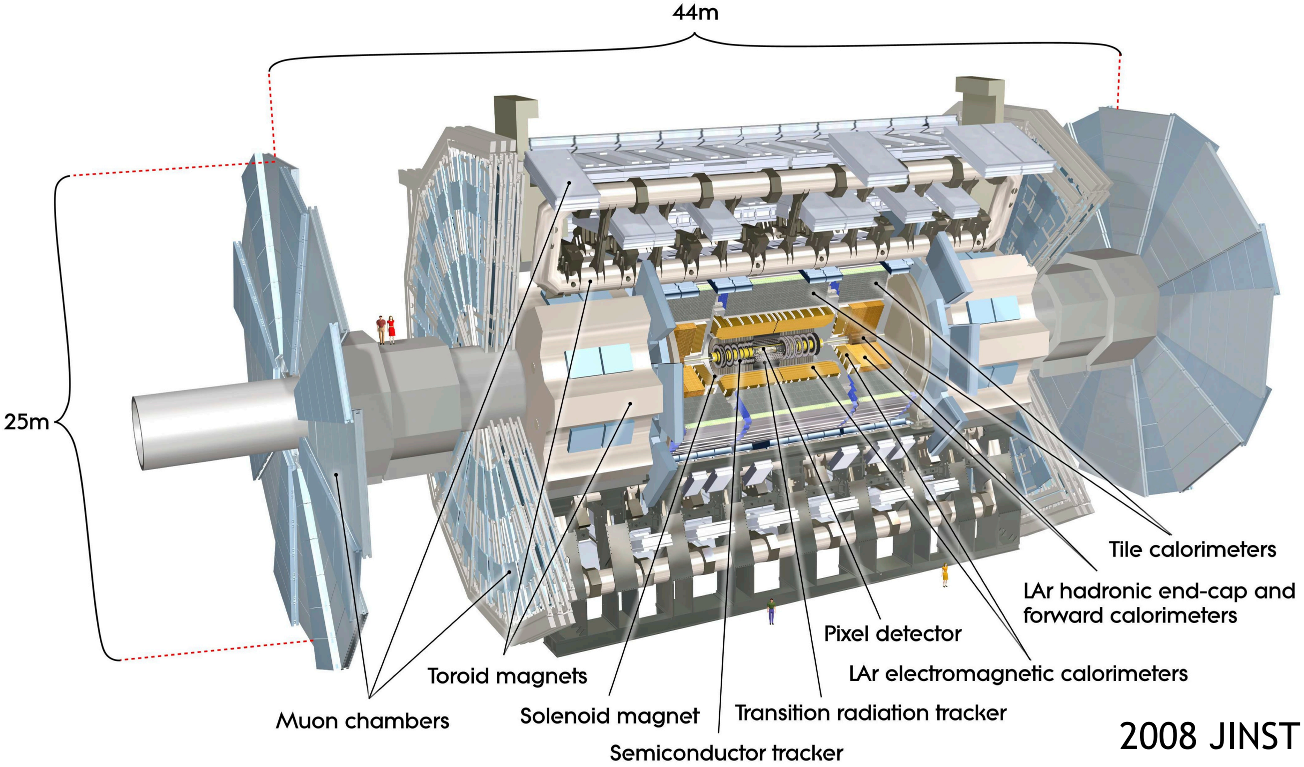
ATLAS



Silicon and straw tracker with transition radiation detection.

Liquid Argon and tile calorimeters.

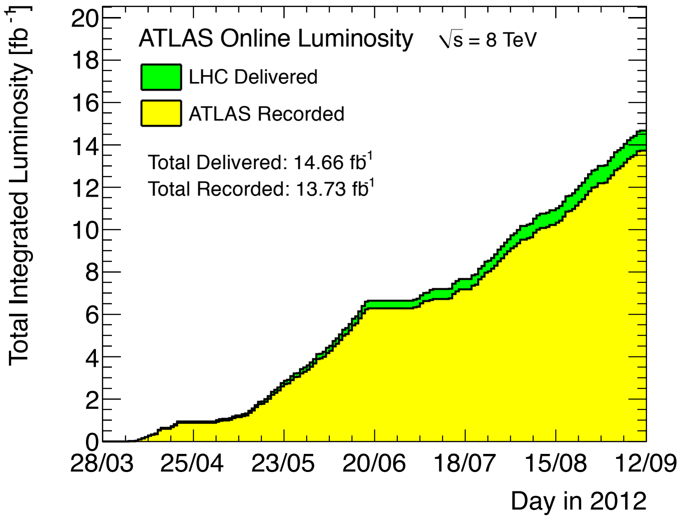
Central 2T solenoid & air-core toroids for muon spectrometer.

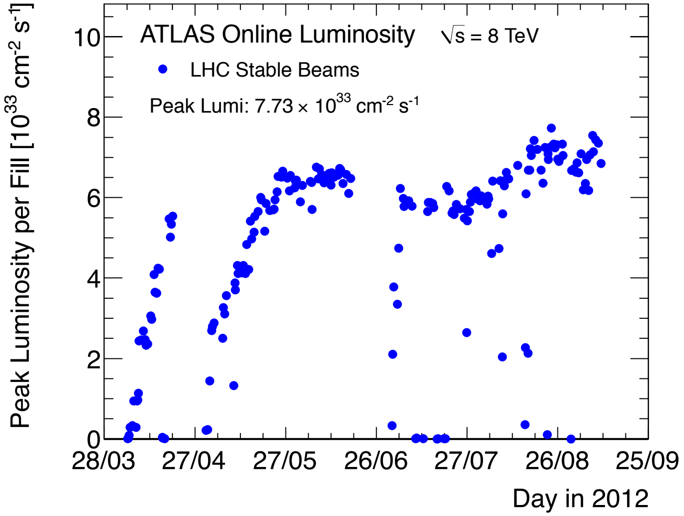


2008 JINST 3 S08003 ATLAS Experiment

Proton-proton data taking

- 5 /fb delivered in 2011 at 7 TeV. Now over 14 /fb at 8 TeV in 2012.
  - Peak luminosity gradually increases
- Data taking efficiency ~94%
  - 24/7 operation, with large teams of on-call experts to support the shift crews
- Data quality: >90% of recorded data is used for physics analysis
  - Large fraction (~99%) of detector channels are operational
- Thousands of jobs running on the grid to calibrate the detectors and then process the data
- This huge effort occupying hundreds of physicists, engineers, technicians is behind every analysis result



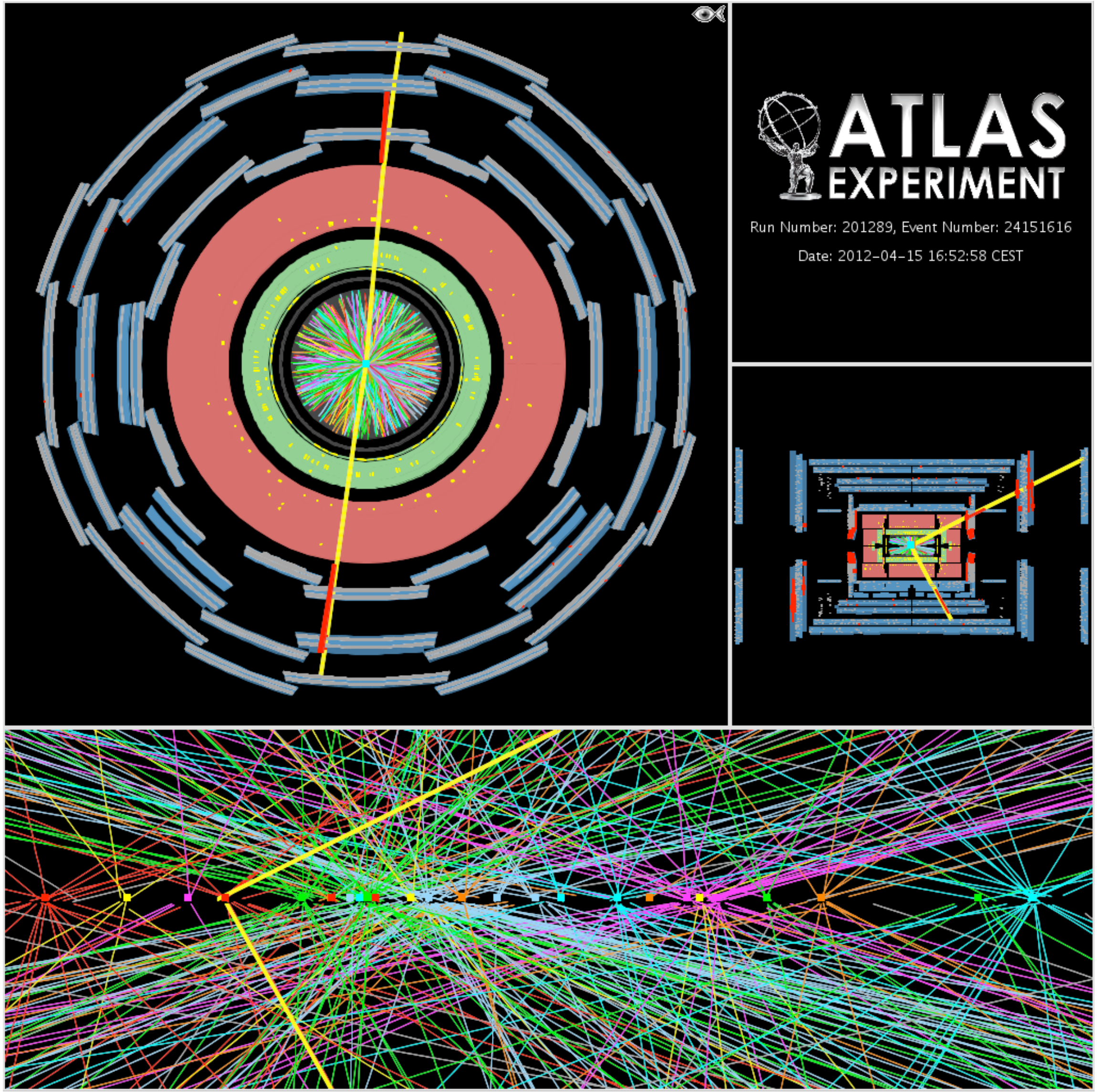


Pile-up

Running with 50 ns bunch spacing.

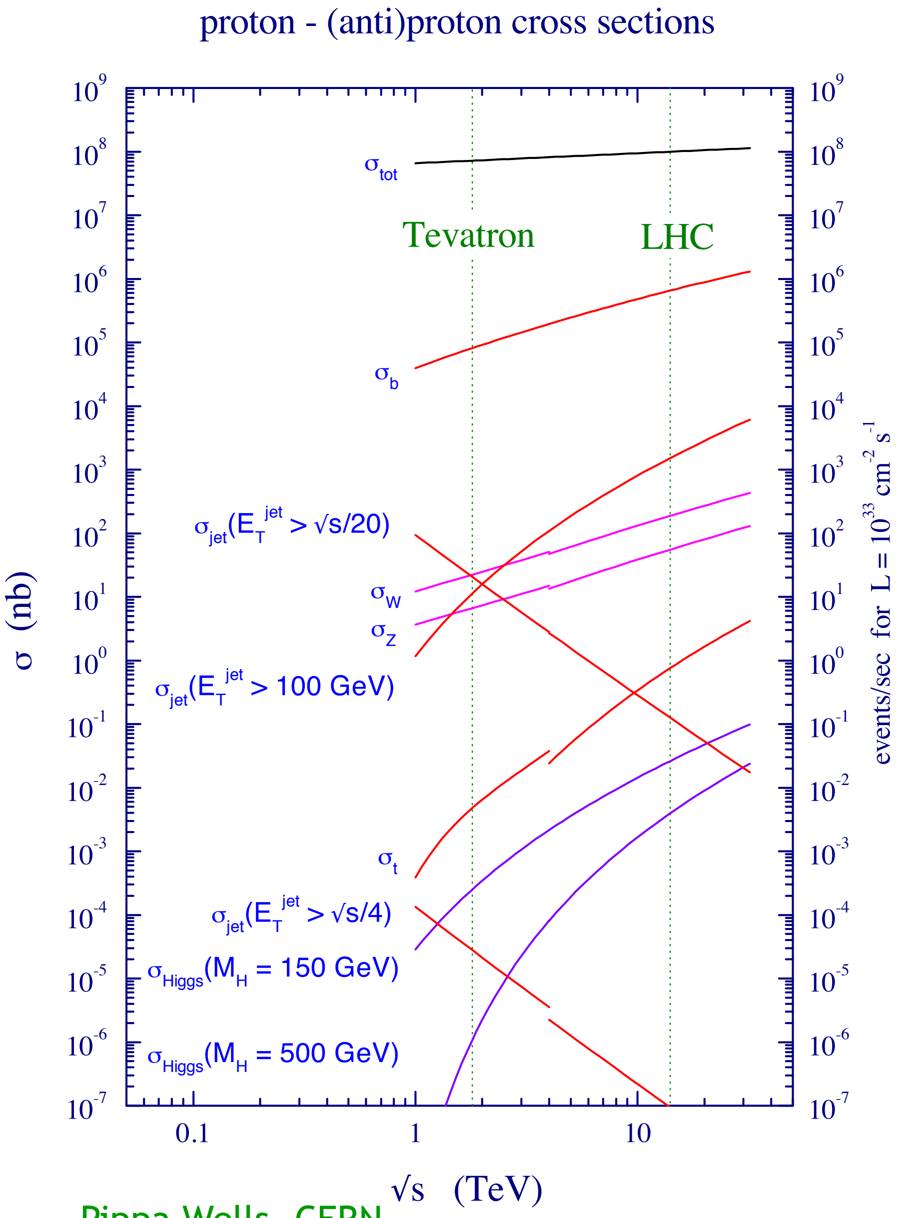
Multiple pp interactions per bunch crossing.

eg. Z→μμ with 25 reconstructed vertices, from 15 April 2012



Production cross-sections at LHC

- Minimum bias cross section is orders of magnitude larger than that of more interesting events.
- Use a multi-level trigger system to decide in real time which events to record (40 million → 400 events per s)
- Trigger menus at LHC are complex, and set minimum thresholds for objects used in analysis



Total

Bottom

Jets

W, Z

Top

Higgs

QCD

Parton density functions F(x,Q^2) describe initial proton constituents

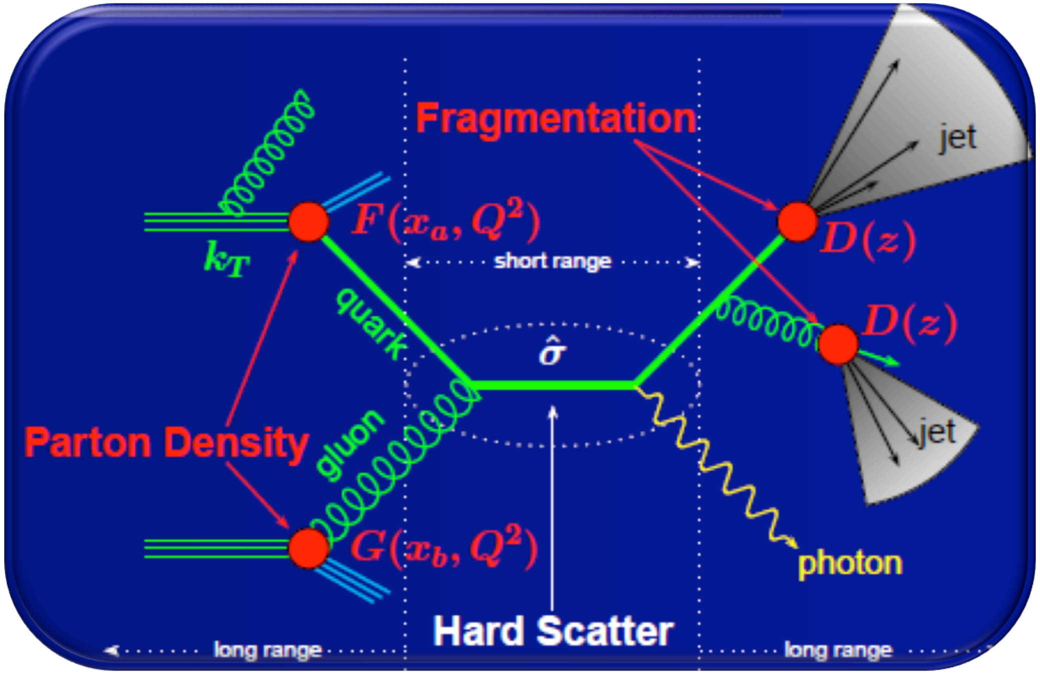
Hard scatter calculated at NLO, NNLO…

Proton remnants create "underlying event"

Hadrons share momentum of final parton in jets.

Fragmentation function D(z) describes individual hadrons.

Final state is simulated by parton shower and hadronisation model

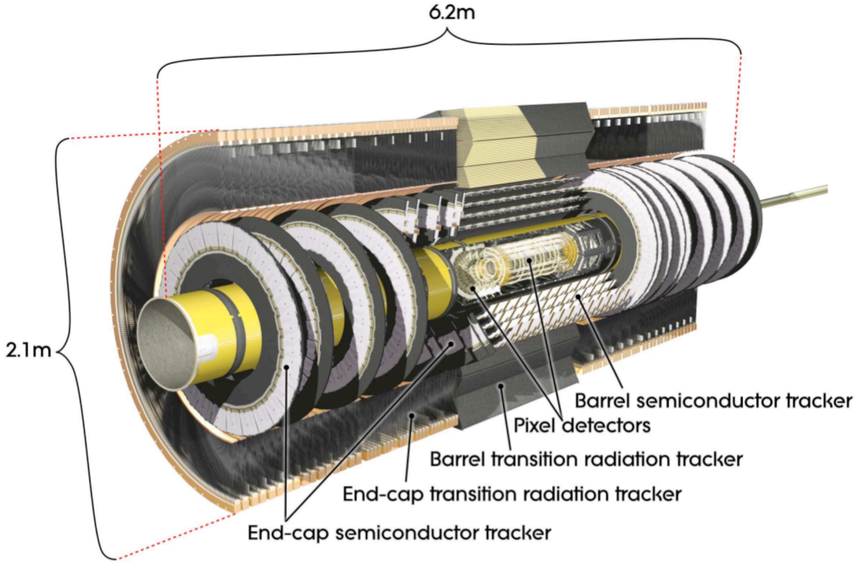


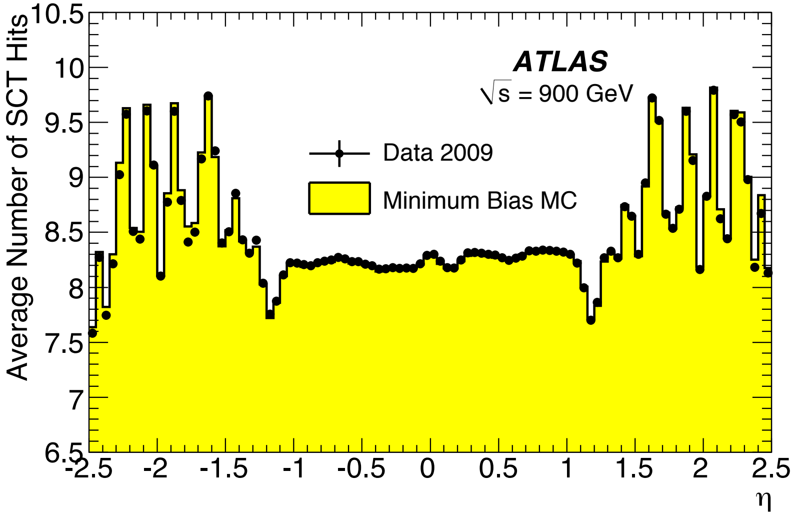
Compare with theory at detector level (Monte Carlo) or after unfolding to NLO+pert. corrections.

Many studies of soft QCD

First measurements at LHC

- First collisions at 900 GeV in 2009, and at 7 TeV in 2010
- Measurements of charged particle production in minimum bias events already required solid understanding of the detector performance
  - Example – detailed modelling of geometry of ATLAS silicon strip detector. Number of endcap discs seen by a track varies with η





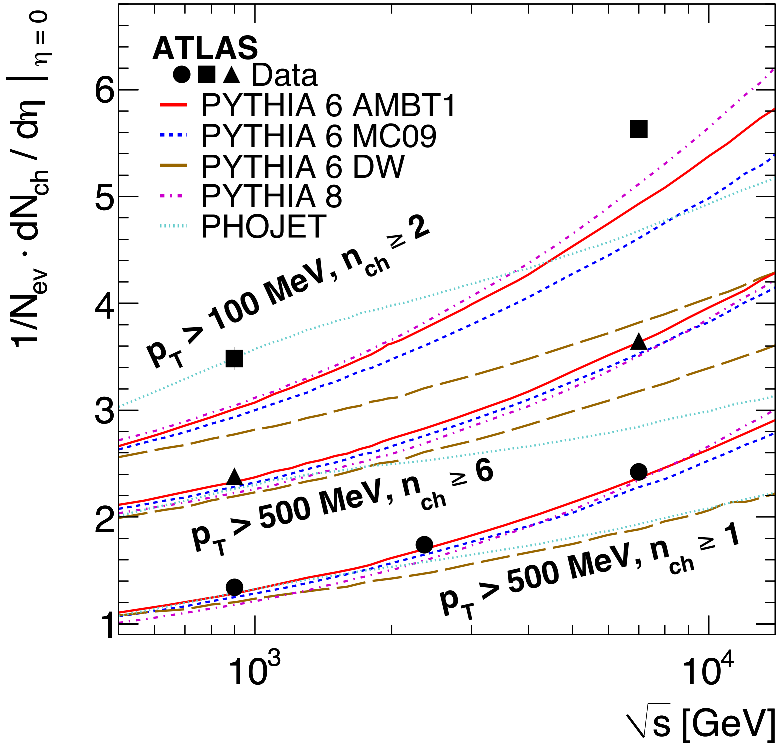
pseudorapidity η = – ln tan (θ/2)

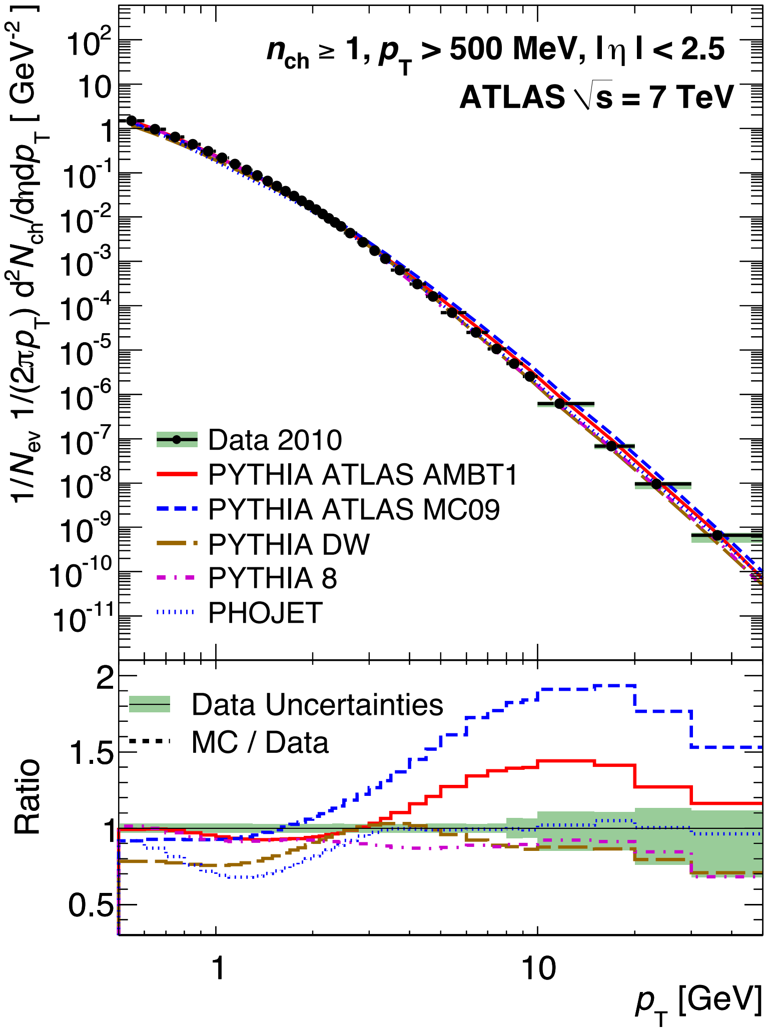
https://twiki.cern.ch/twiki/bin/view/AtlasPublic

ATLAS arXiv:1012.5104 [hep-ex]

Hadron production

- Many detailed measurements of the properties of minimum bias events. Made with low integrated luminosity and low pileup.
- eg. charged particle density and p_T ($p_T = p \sin \theta$)

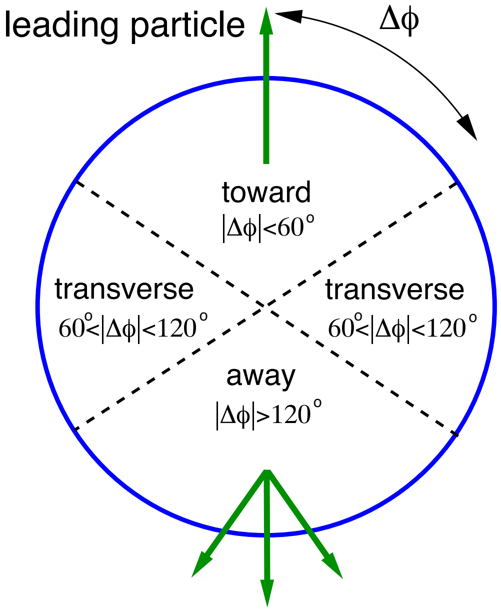


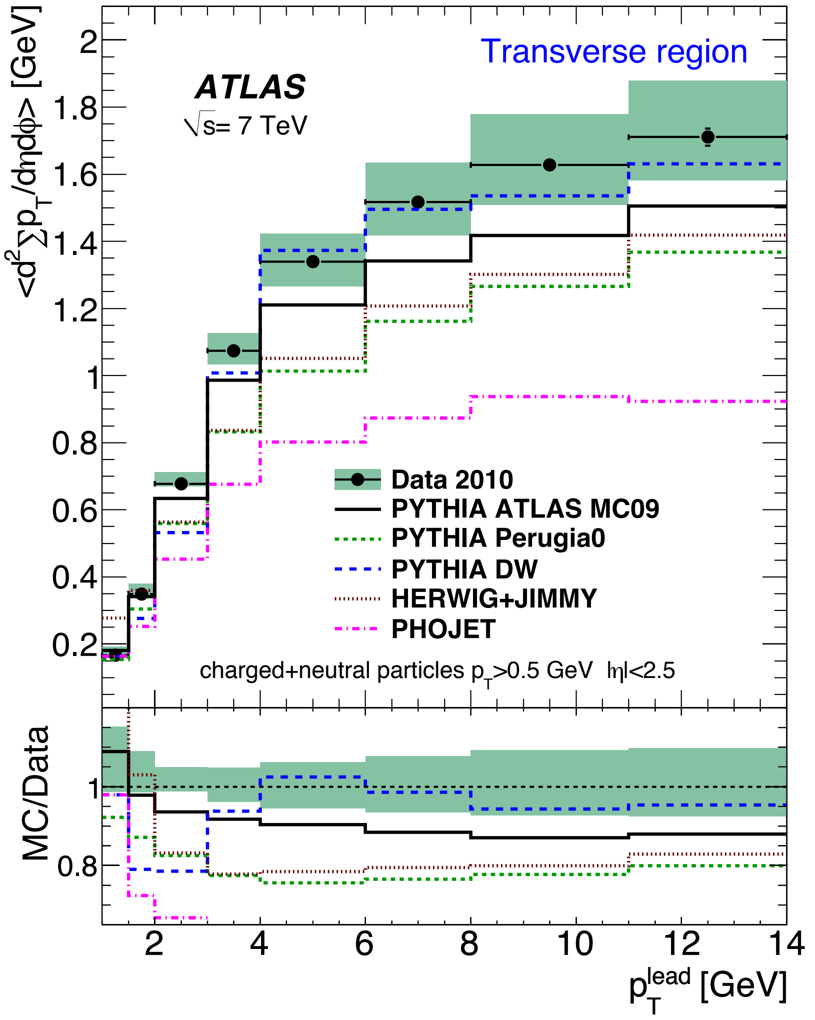


ATLAS arXiv:1103.1816v2 [hep-ex]

Underlying Event

- Look in the region away from the leading track at
- eg. average p_T of tracks vs. leading track p_T compared to Monte Carlo.





Jet finding

- Use the anti_k_t algorithm. Distance parameter R in the (ϕ,y) plane

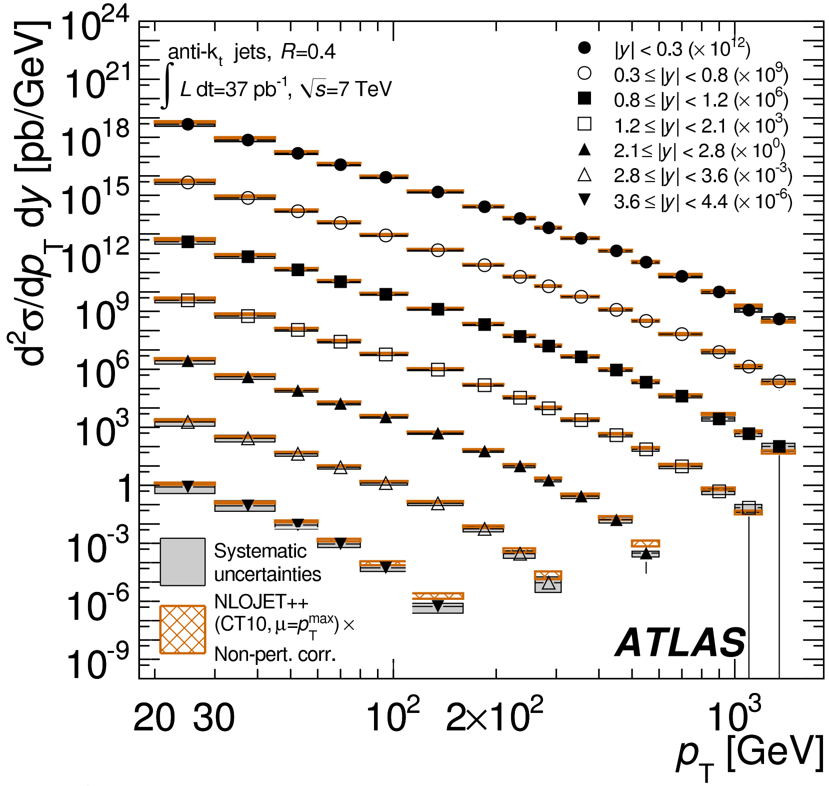
$$d_{ij} = \min\left(\frac{1}{k_{ti}^2}, \frac{1}{k_{tj}^2}\right)\frac{\Delta\phi^2 + \Delta y^2}{R^2} \;;\; d_{i,beam} = \frac{1}{k_{ti}^2}$$

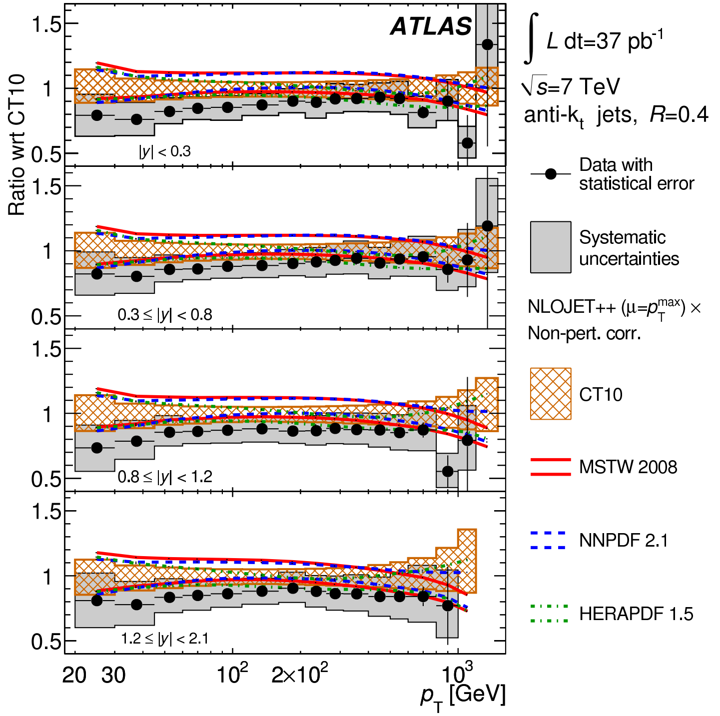
  - Merge the pair of particles with minimum d_{ij}; or if $d_{i,beam}$ is the smallest, ith object becomes a jet.
- Detector level jets from 3-d topological calo. clusters at EM scale
  - Correct for contributions from pile-up events, instrumental noise, dead channels, beam-related background.
  - Correct to hadronic scale using η and E dependent factors from simulation, and cross-checked with data
  - EM scale improved with Z→ee events
  - Study single particle response in collision data and test-beam
  - Verify energy scale with track-jet match, and with momentum balance in γ-jet, dijet and multijet events
  - Jet energy scale (JES) uncertainty 2.5 to 4.6% for central η (2010)

ATLAS arXiv:1112.6297 [hep-ex]

Inclusive jet production

- Individual jets with p_T greater than 1 TeV, |y| to 4.4
  - Experimental systematic uncertainty ~ 10-20%
- Compare to NLO x non-pert. corrections – agree within errors
  - Central pdfs: CTEQ.6
  - Ratio plot shows data/theory ratio



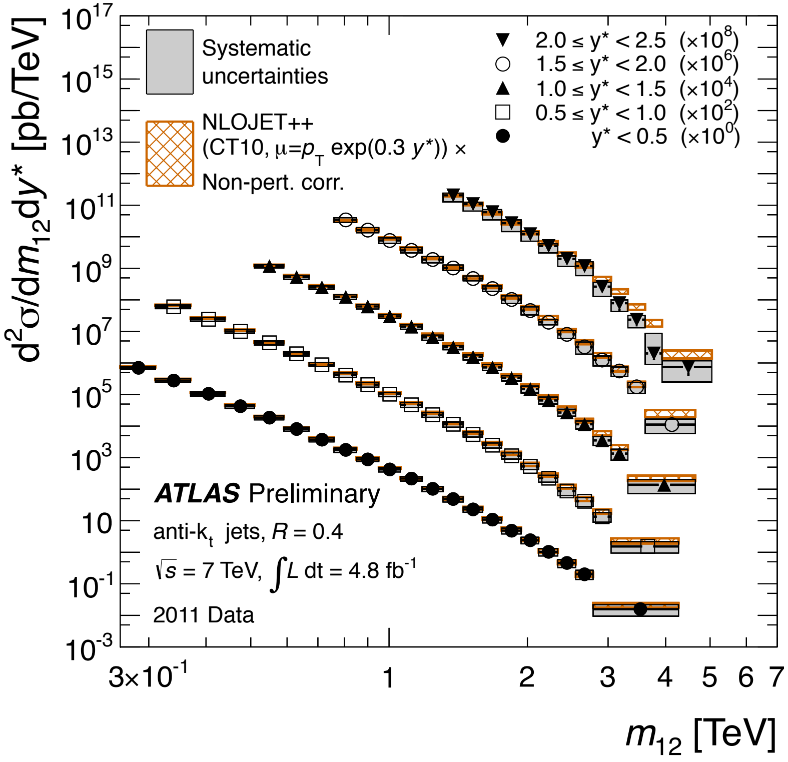


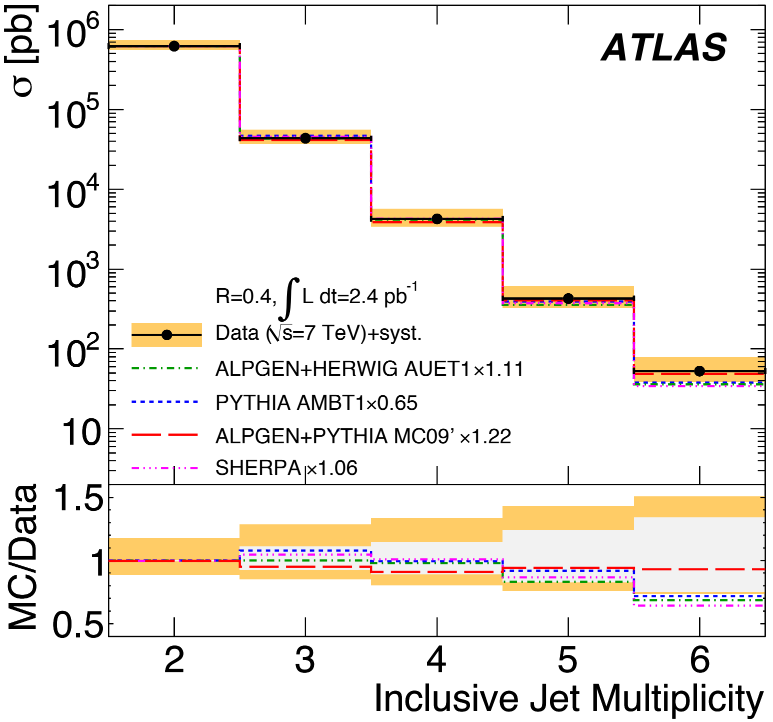
ATLAS arXiv:1107.2092 [hep-ex]

Di-jets, multijets

Dijet mass spectrum extends to ~4 TeV

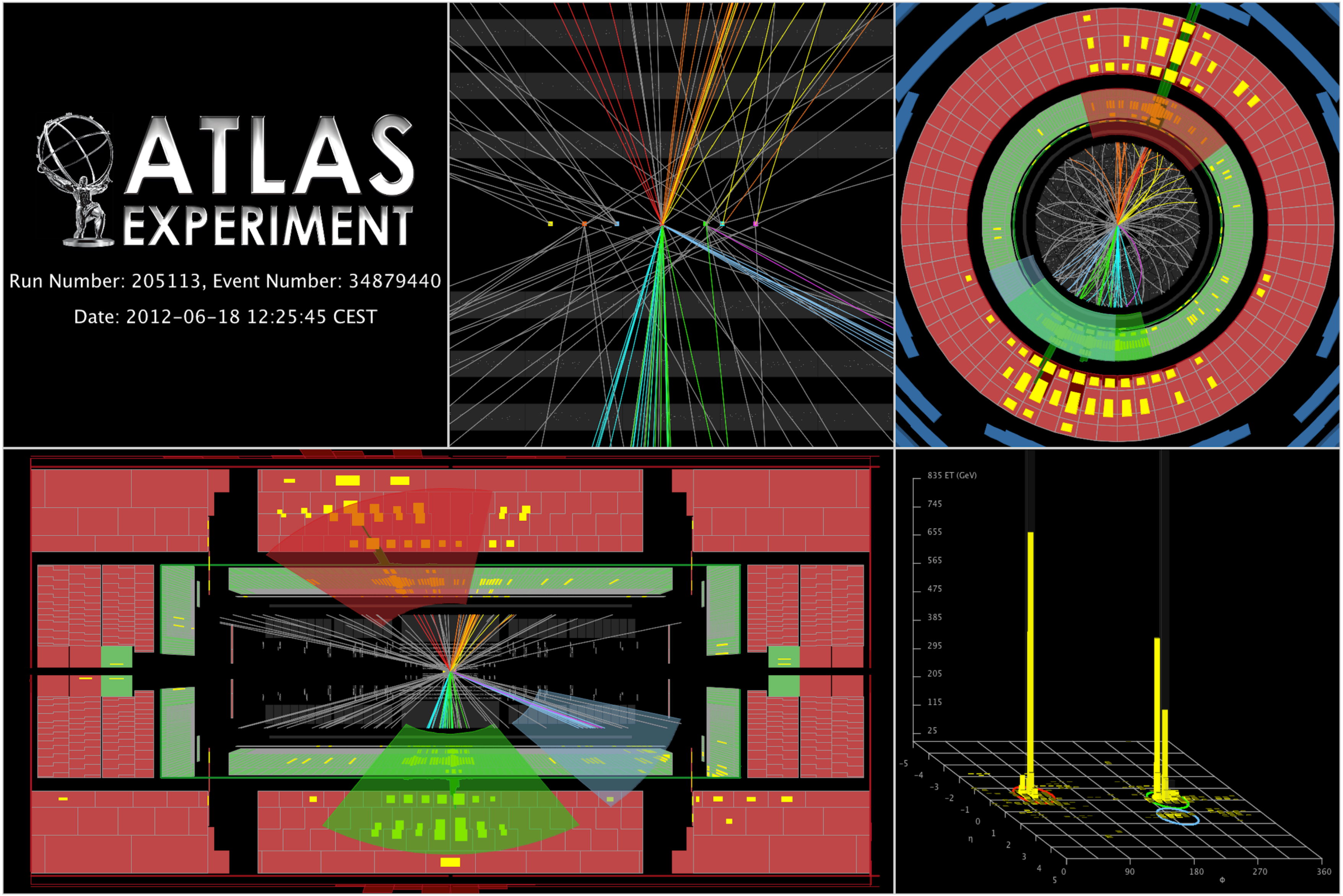
Rate and p_T distributions of multijets also studied.





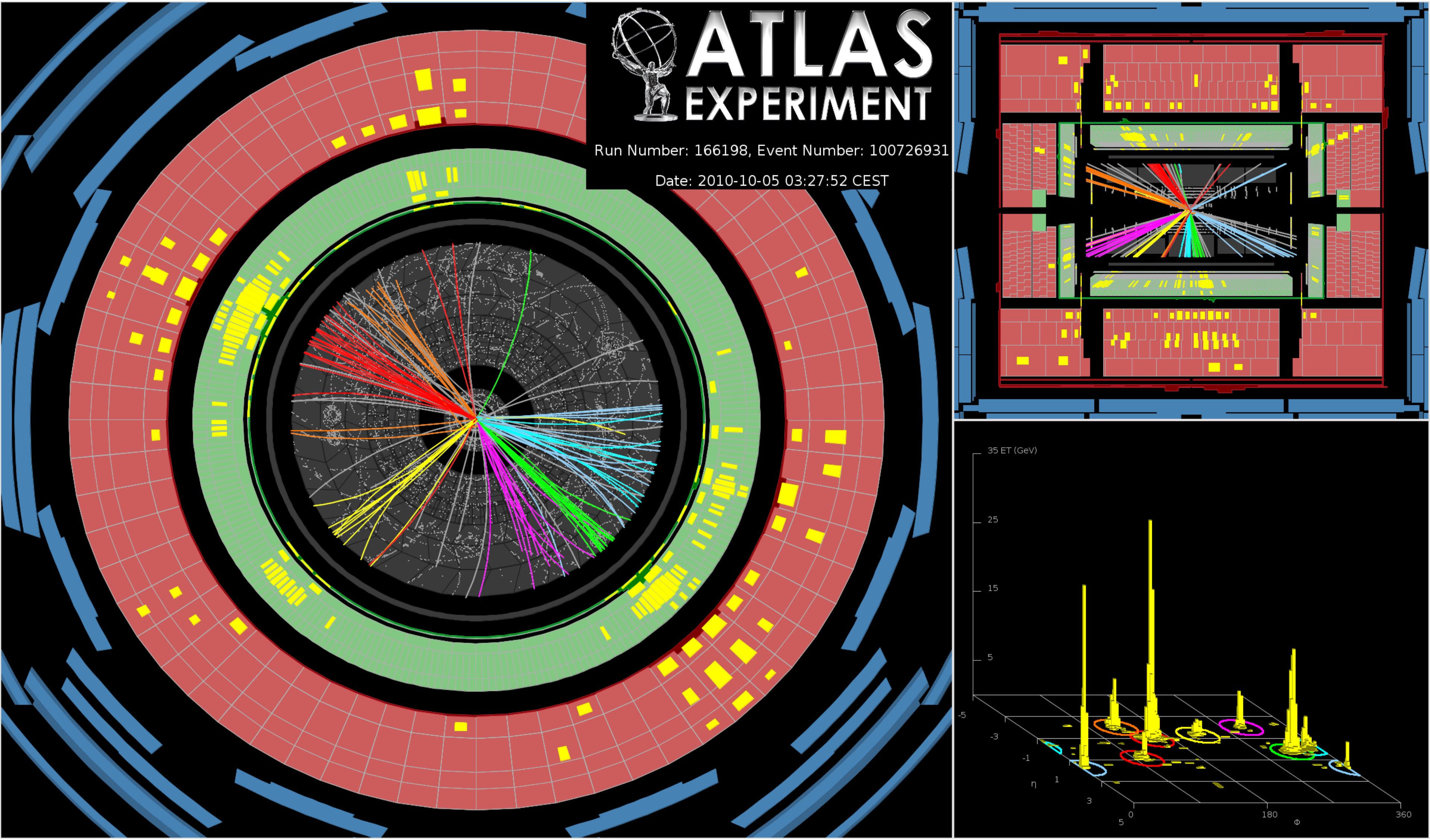
High mass di-jet

p_T jet1=2.1 TeV, p_T jet2=1.9 TeV
m_{jj}=4.1 TeV



8-jet event

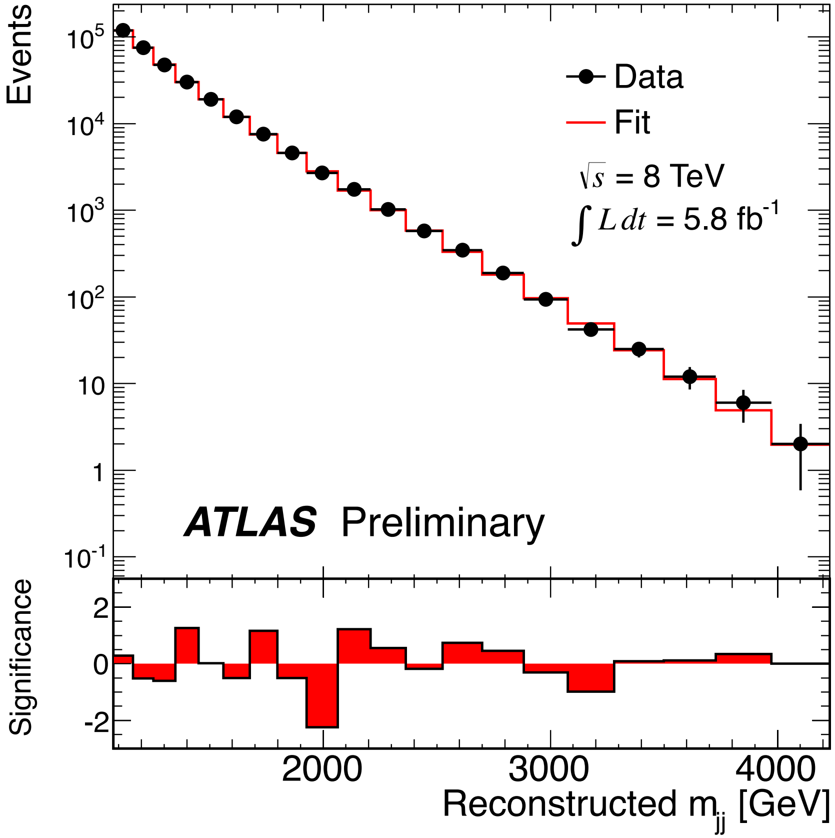
8 jets with p_T>60 GeV

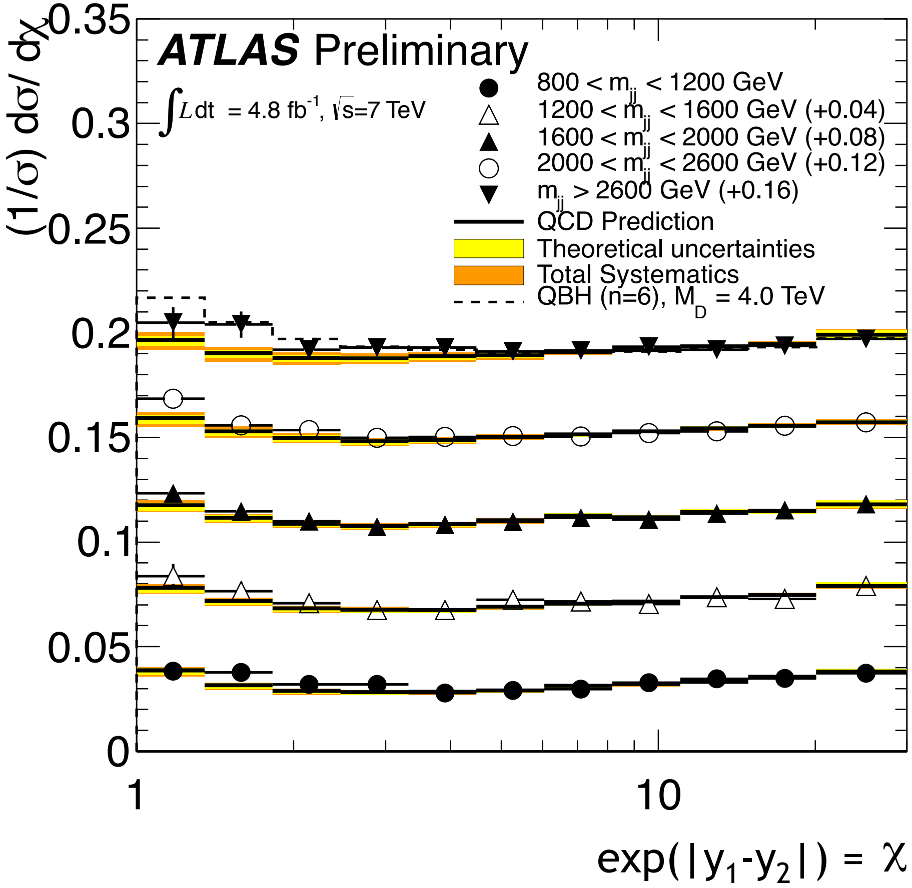


ATLAS-CONF-2012-088
ATLAS-CONF-2012-038

Searches with dijets

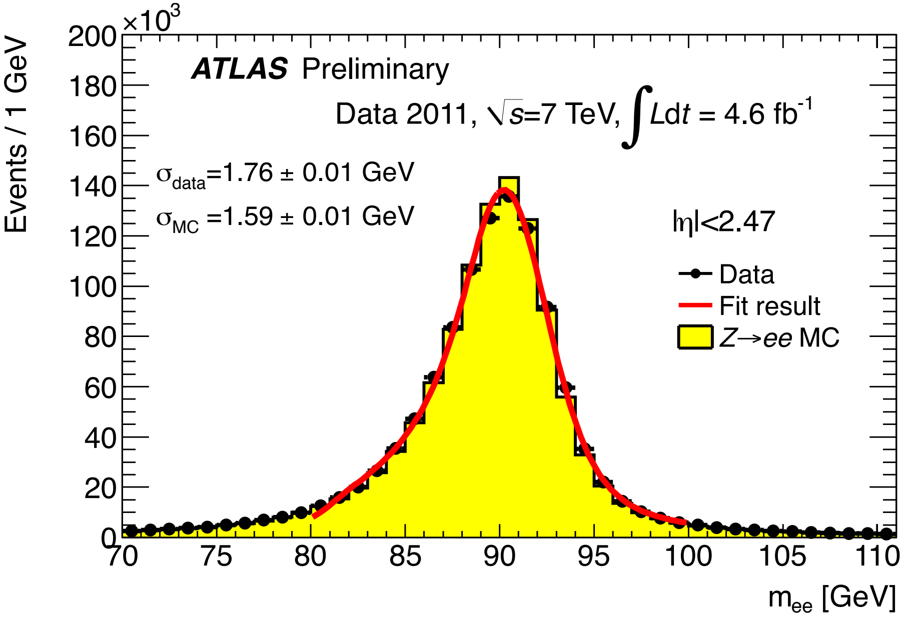
- Examine dijet mass spectrum. No significant bumps. Excited quark with m < 3.66 TeV excluded at 95% CL
- From angular variables, exclude contact interactions up to 7.8 TeV

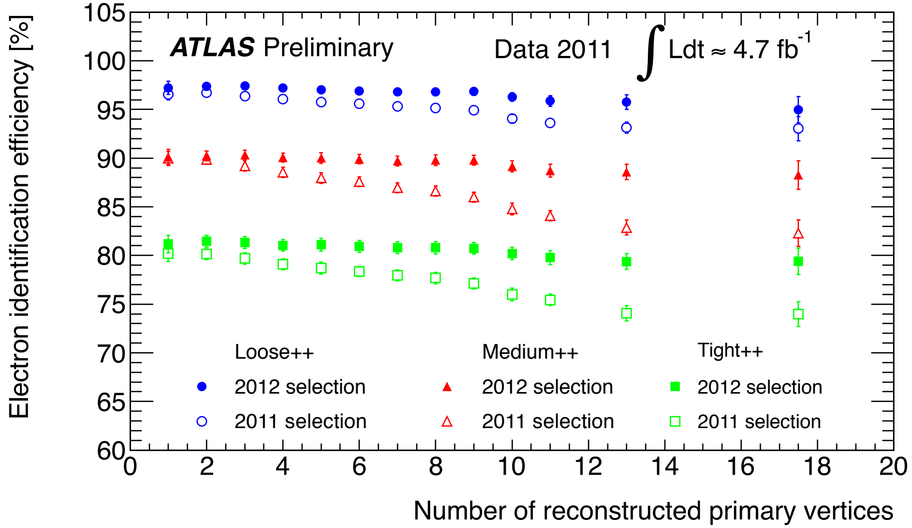




Electron identification

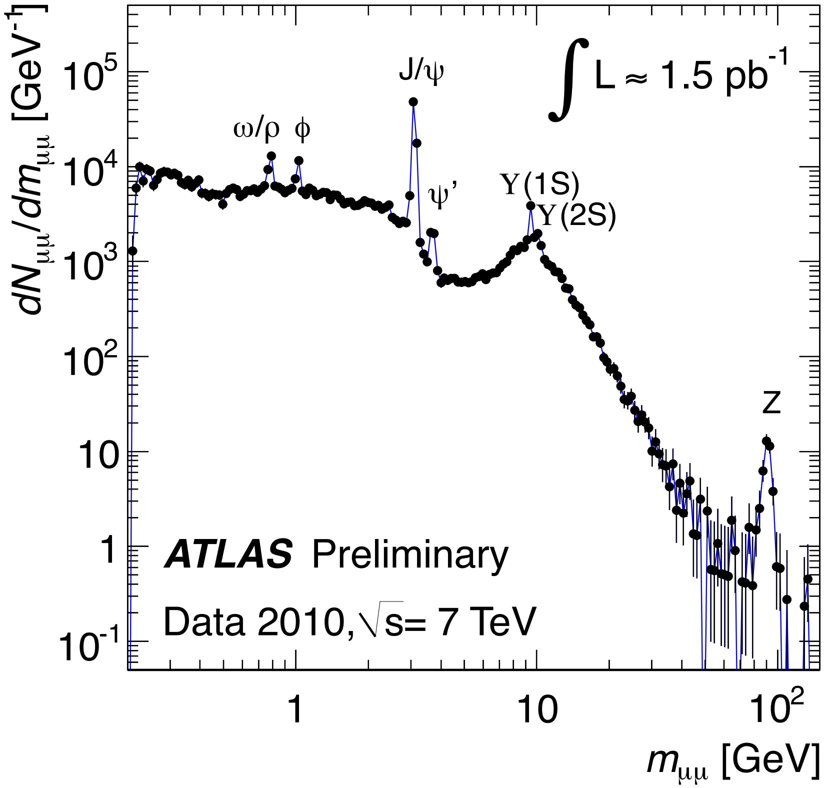
- Start with calo cluster
  - Track matching cluster
  - Shower shape and isolation
  - E/p = 1 (cluster energy/track momentum)
  - Transition radiation
  - Improve reconstruction by finding Bremsstrahlung photons
- Algorithms refined to be robust against pileup





Muons, taus…

- Muons
  - Matched track segments in inner detector and muon spectrometer (MS)
  - MS improves resolution for high p_T muons
  - May also match a track with minimal energy loss in the calorimeter to recover low momentum muons, or in areas with no muon chambers
- Taus
  - Narrow jet:1-prong and 3-prong hadronic decays
  - Decays to e or μ + ν's



eg. muon pair mass spectrum with known resonances

Verify momentum calibration and look for new states, eg. Z'

Invisible particles

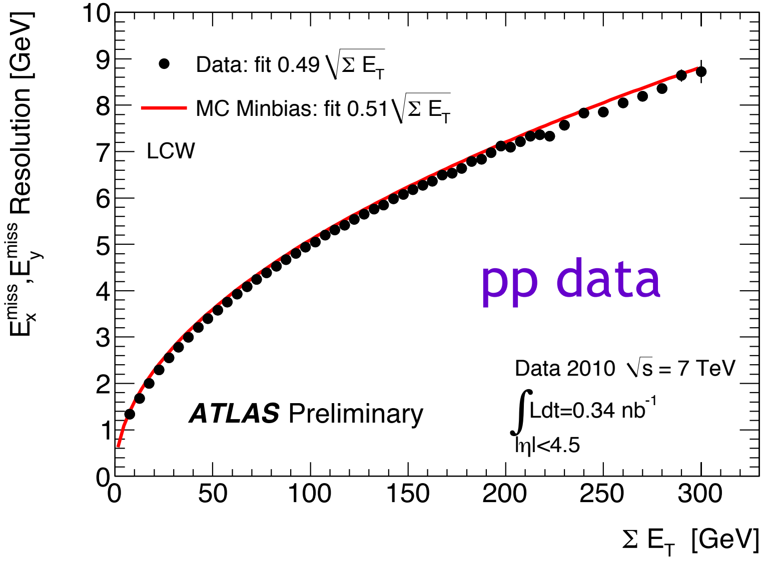
$$\vec{E}_T^{miss} = -\sum_i \vec{p}_T^{\,i}$$

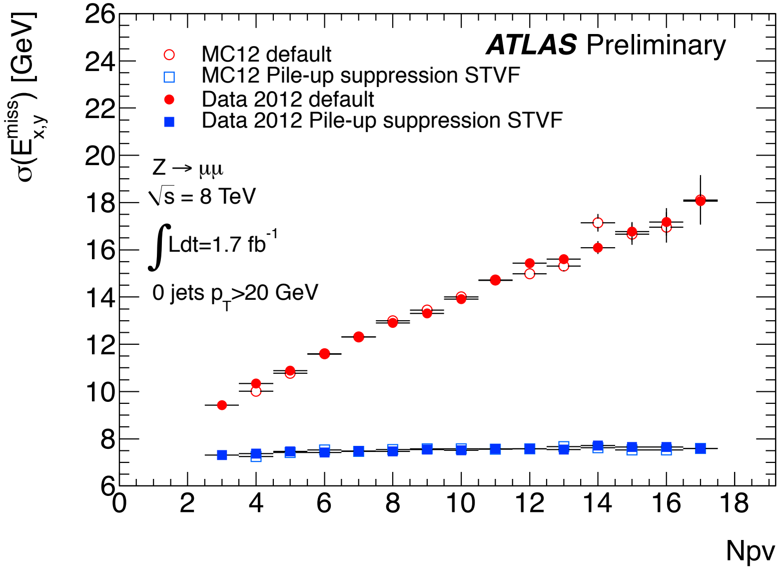
ATLAS E_T^{miss} resolution $0.5\sqrt{\Sigma E_T}$ up to ΣE_T of 14 TeV for calo-only

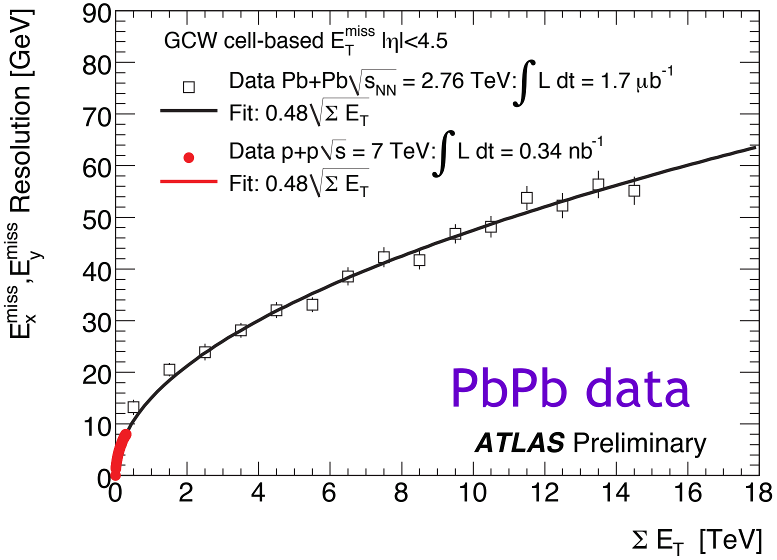
Improve resolution by using the correct energy scale for identified e, μ, jets etc.

Use tracking to make algorithms more robust against pile-up

Resolution 5GeV for ΣE_T 100GeV



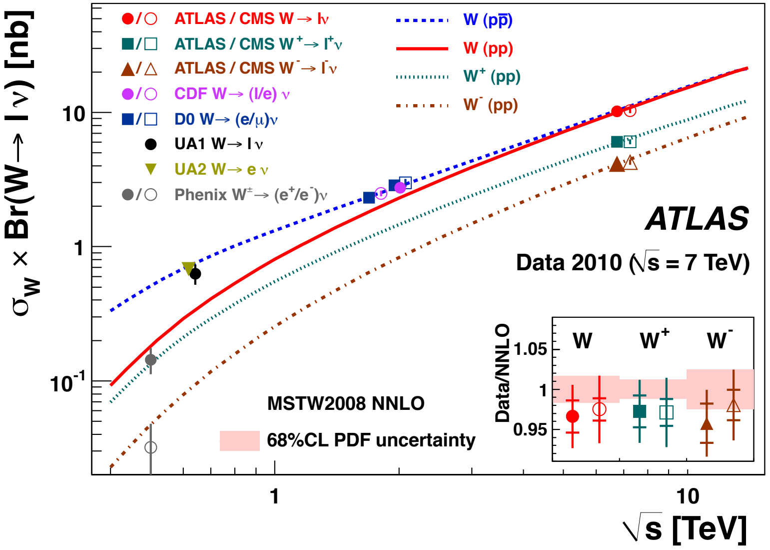


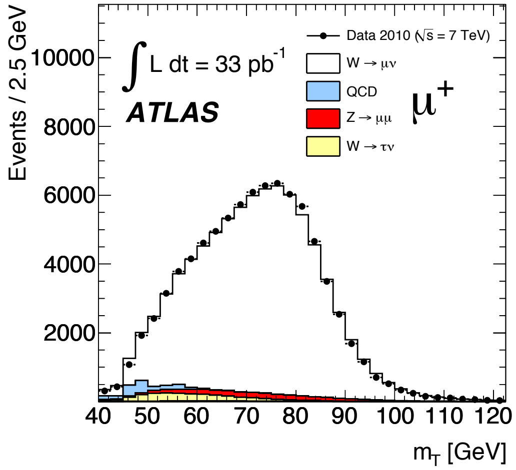


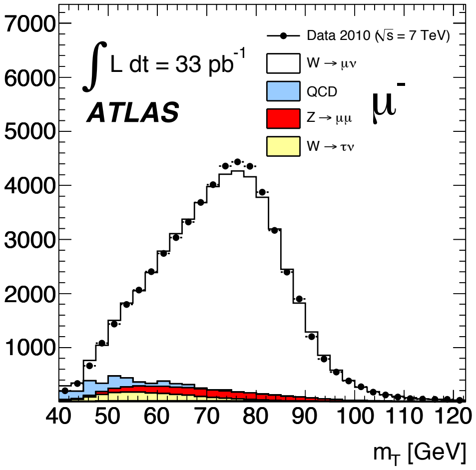
ATLAS Phys. Rev. D85 (2012) 072004

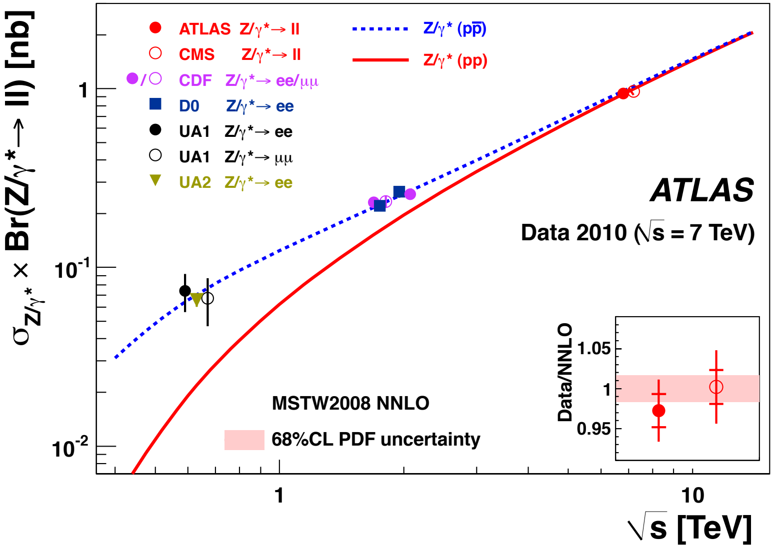
W and Z production

- W → charged lepton and E_T^{miss}
- Calculate transverse mass of lepton-neutrino system
- Z → same flavour charged leptons.
- W and Z to e, μ, τ all measured
- Hadronic decays swamped by QCD
- Some uncertainties cancel in W^+/W^- and W/Z ratios





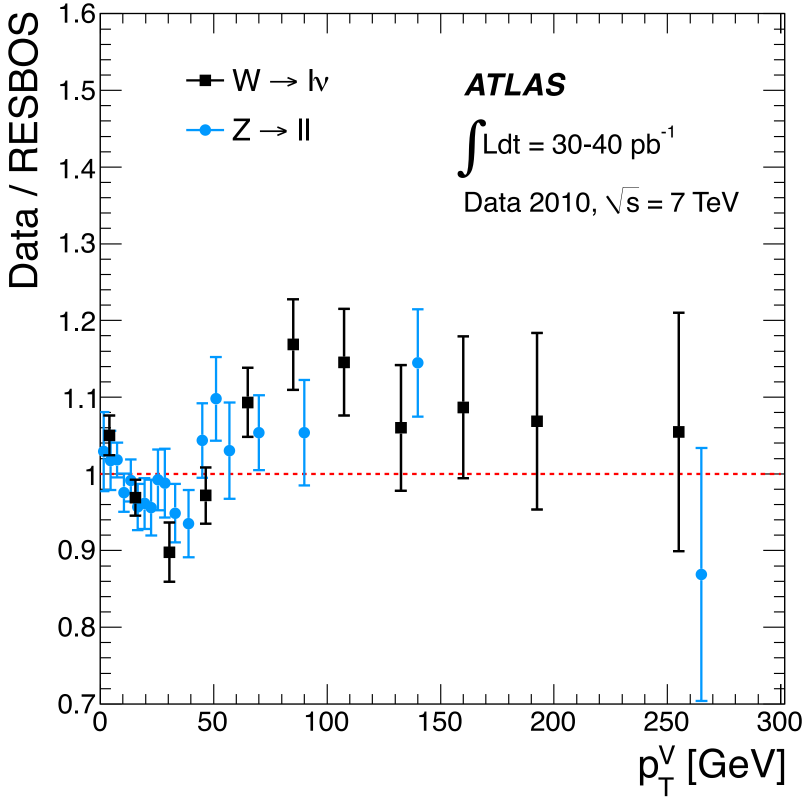




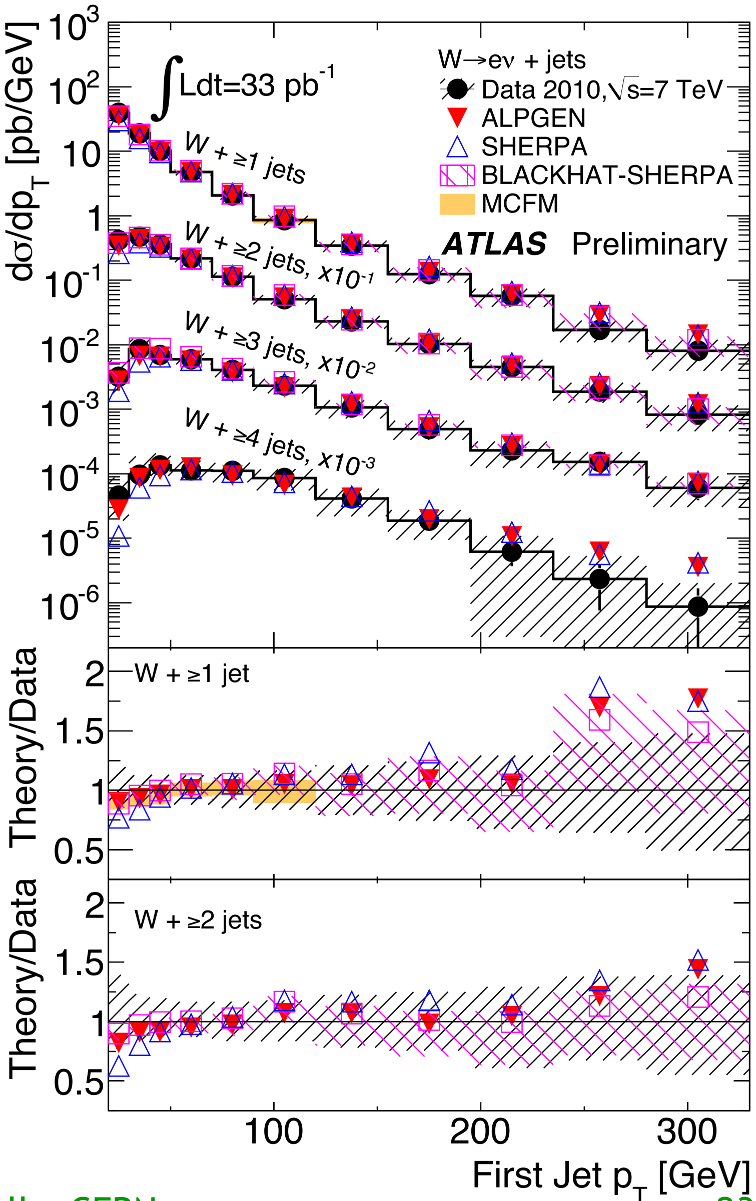
ATLAS arXiv:1108.6308 [hep-ex]
ATLAS-CONF-2011-060

W,Z p_T spectrum & associated jets

$p_T(Z)$ & $p_T(W)$ both measured.
W,Z + jets is also well described



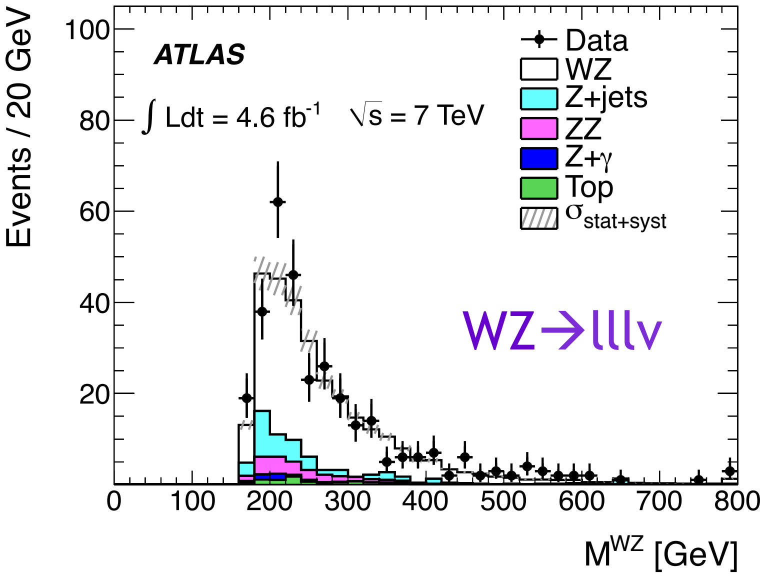
Similar deviations for W and Z

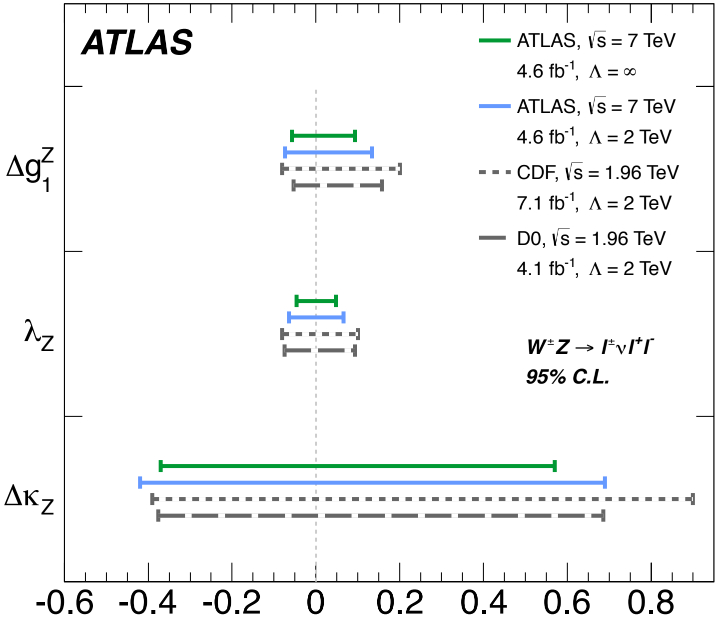


arXiv:1208.1390 [hep-ex]

Diboson production

- Measure Wγ, Zγ, WW, WZ and ZZ final states
- WW→lvlv, WZ→lllv, ZZ→llll all observed.
  - More difficult to distinguish WW/WZ → lvjj (V+jets background)
- Check for anomalous triple gauge couplings
  - charged TGCs: WWγ, WWZ non-zero in the Standard Model
  - neutral TGCs: ZZγ, Z$\gamma\gamma$, are zero
  - No deviations from SM observed

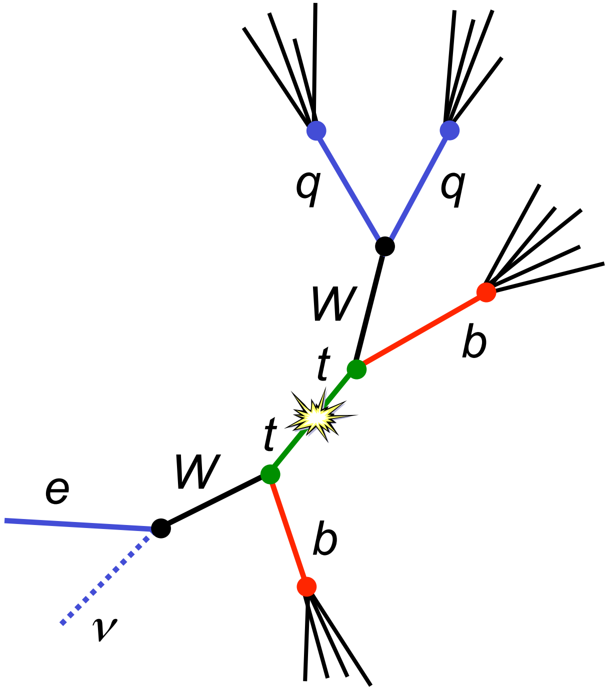


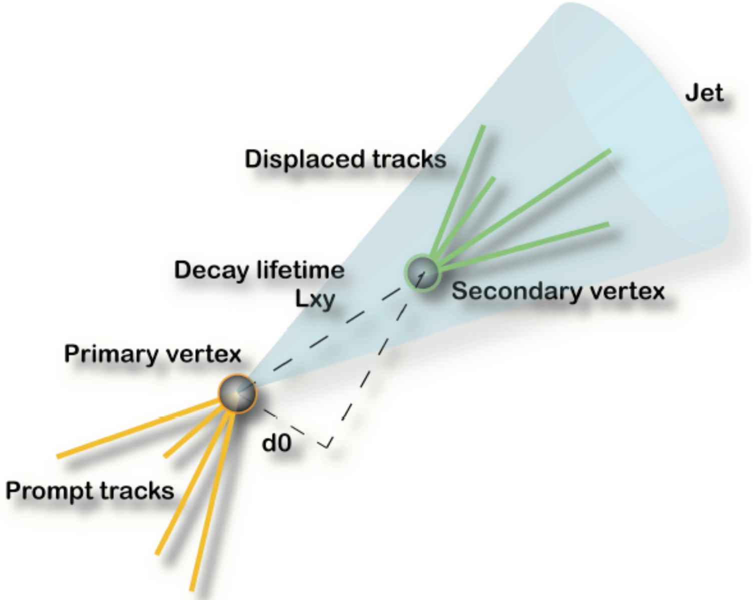


ATLAS constraints tighter than Tevatron

Top quark pair production

- Top decays to Wb (~100%). Events characterised by W decays. Leptons, jets and E_T^{miss}, plus b-jets.





B-tagging:

Tracks have significant impact parameter, d_0.

May reconstruct secondary vertex with characteristic mass.

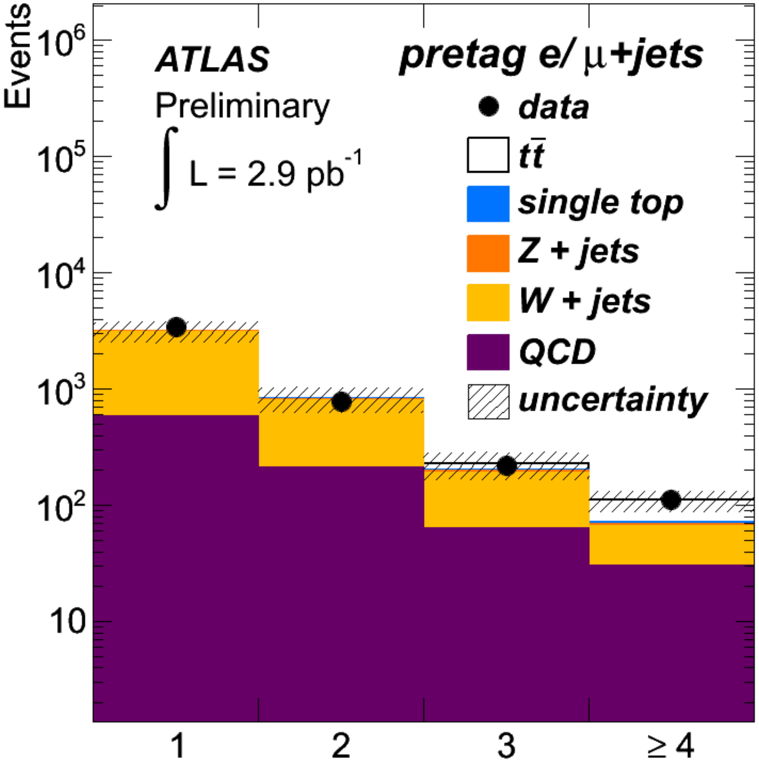
Soft muons: from weak decays

Early example (2010): single lepton channel

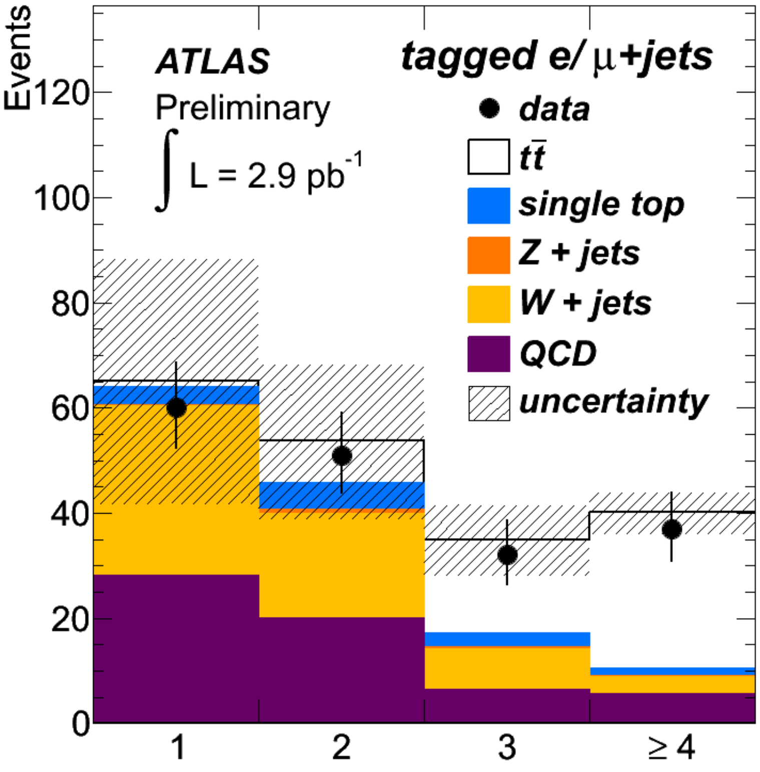
1 e or μ with p_T>20 GeV, E_T^{miss}>20 GeV, $E_T^{miss}+m_T(W)$>60 GeV

N_{jets} with p_T>25 GeV, with no b-tag requirement or at least one b-tag

Signal defined to have 4 or more jets, and at least 1 b-tag



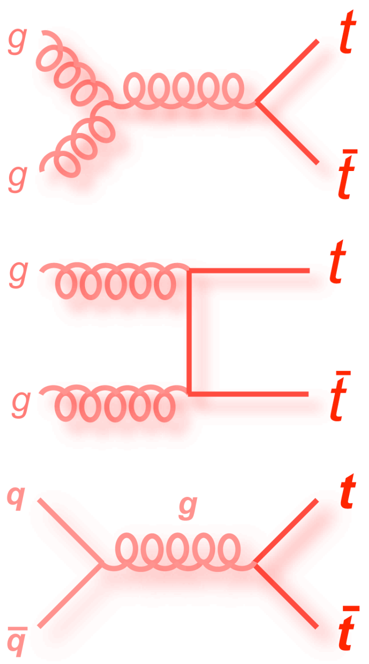
No b-tag (log scale)

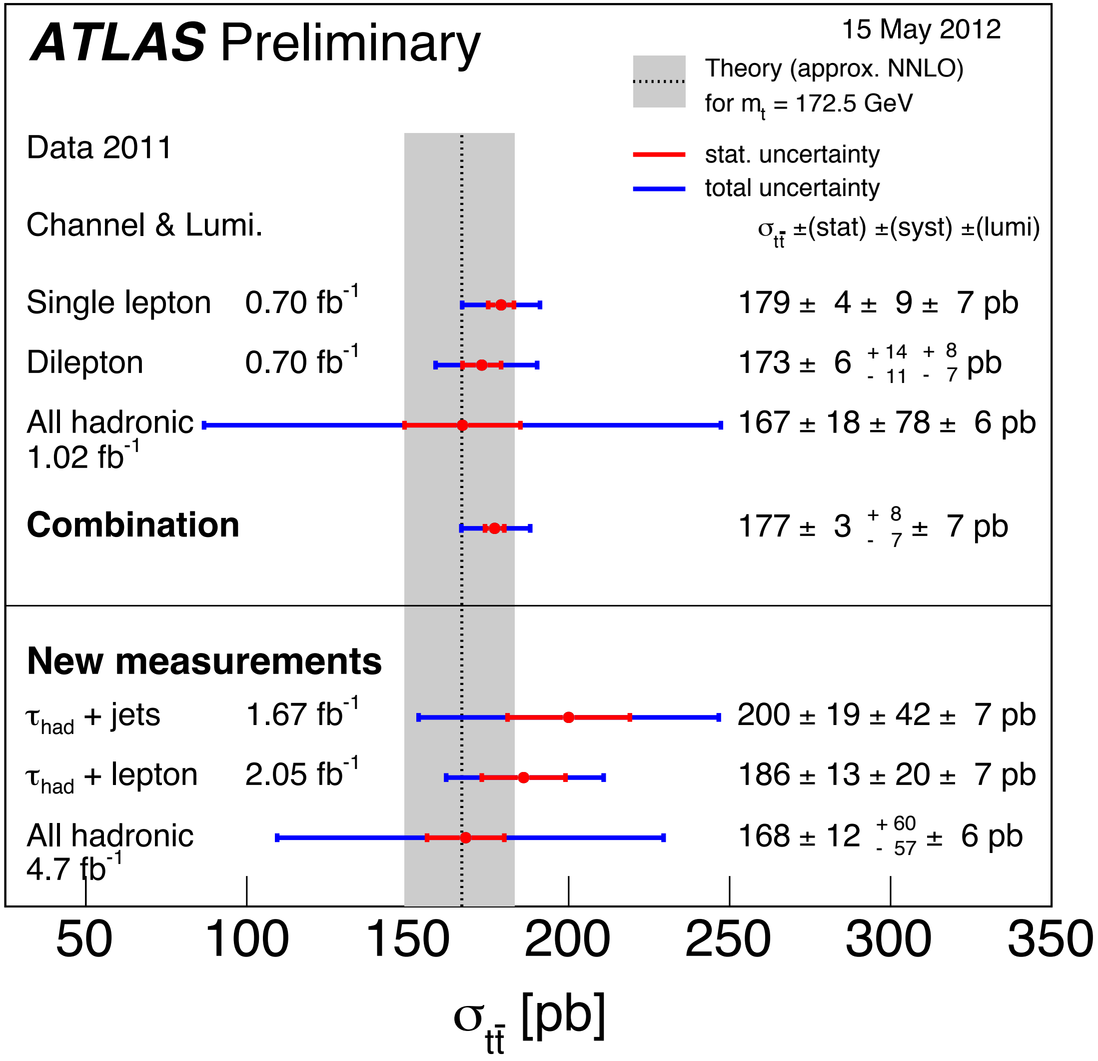


At least one b-tag

Latest top pair cross section results

6% relative precision

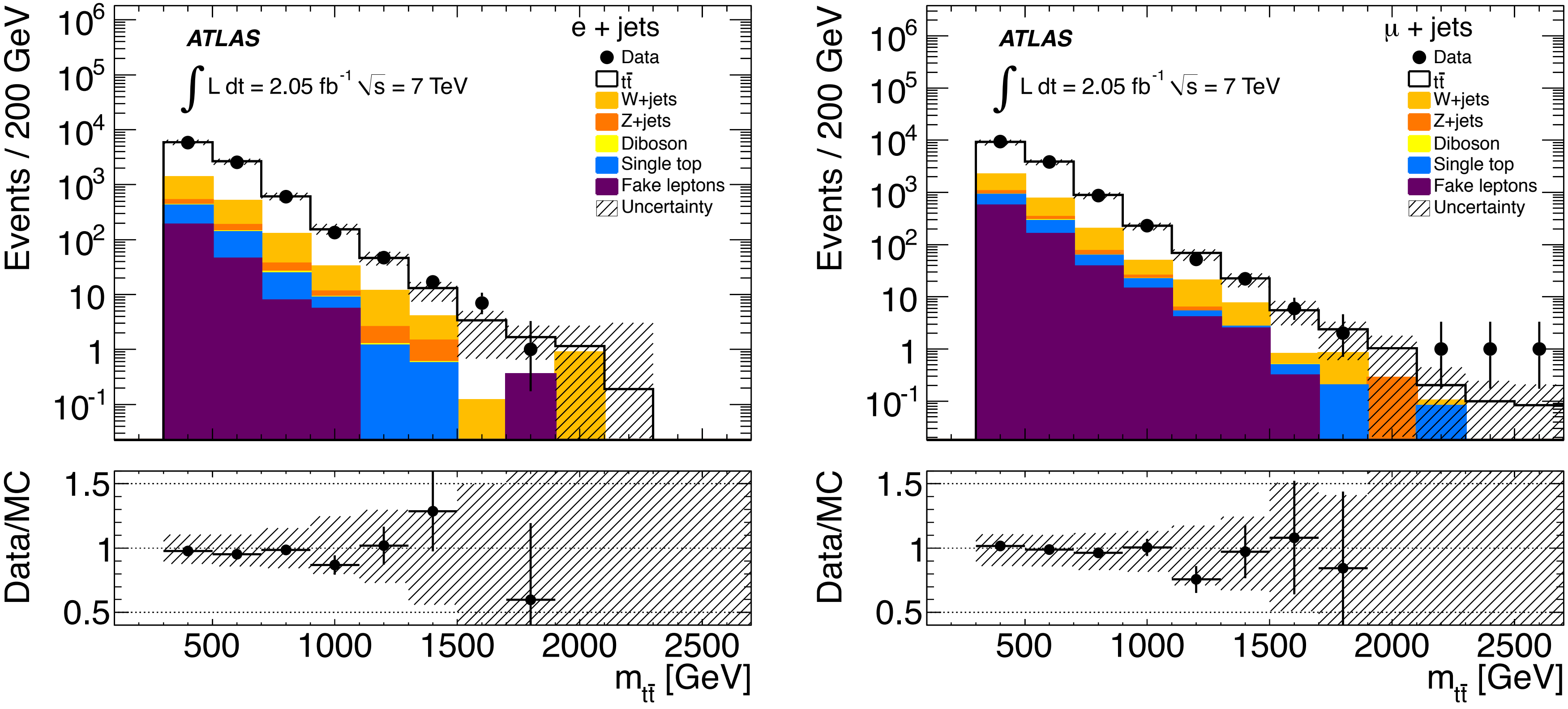




arXiv:1207.5644 [hep-ex]

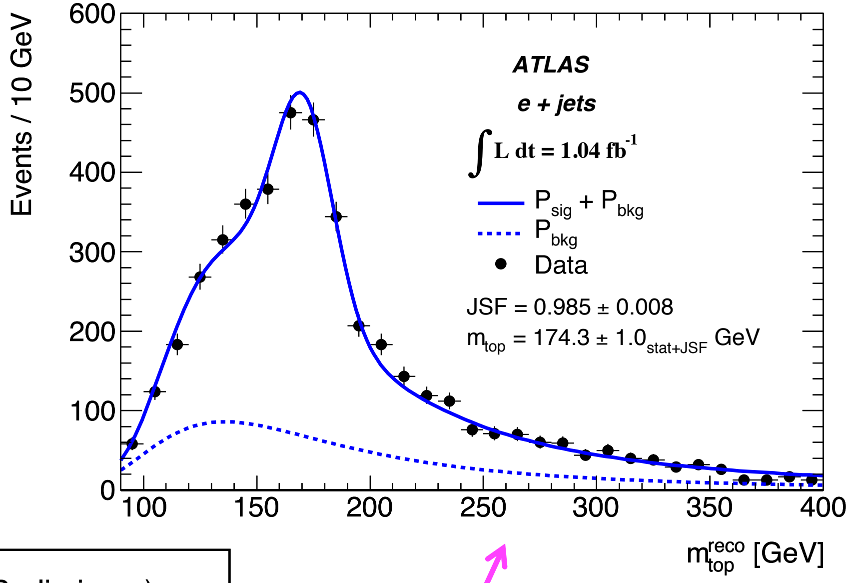
Differential cross sections

Example: Production cross section as a function of ttbar mass

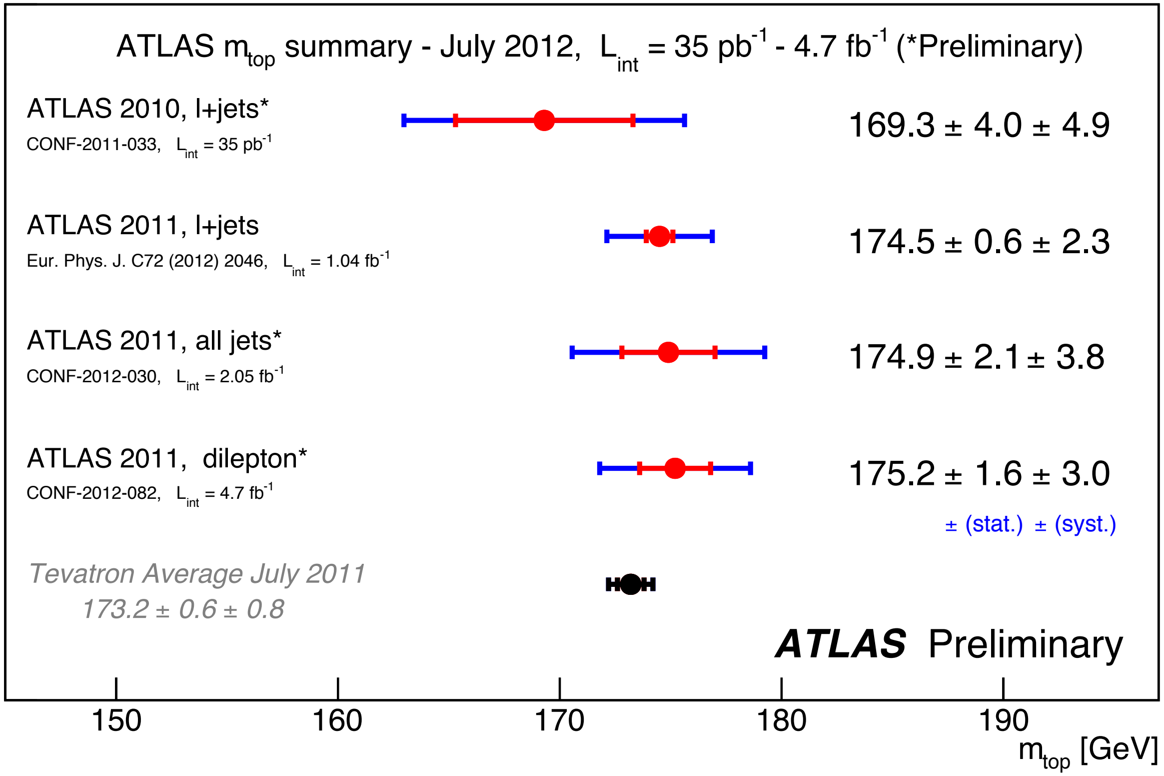


Top quark mass

- Top mass from reconstructed events: uncertainty ±3 GeV.
- Dominant uncertainty is jet energy scale, in particular the b-jet energy scale



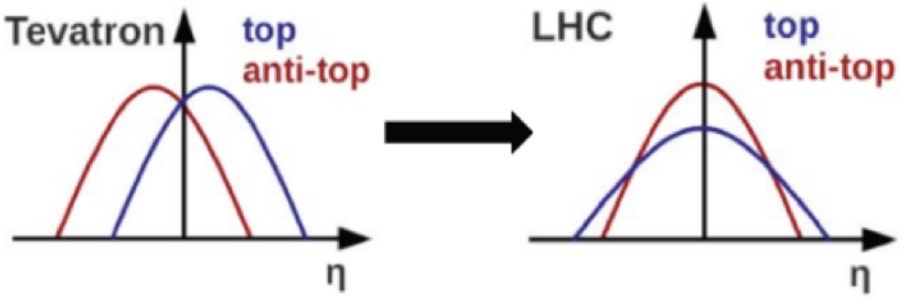
Most precise: lepton+jets
arXiv:1203.5755 [hep-ex]



arXiv:1203.4211 [hep-ex]

Top charge asymmetry

Top charge asymmetry from (pseudo-)rapidity difference between t and tbar – quark tends to have larger |η| or |y| at LHC



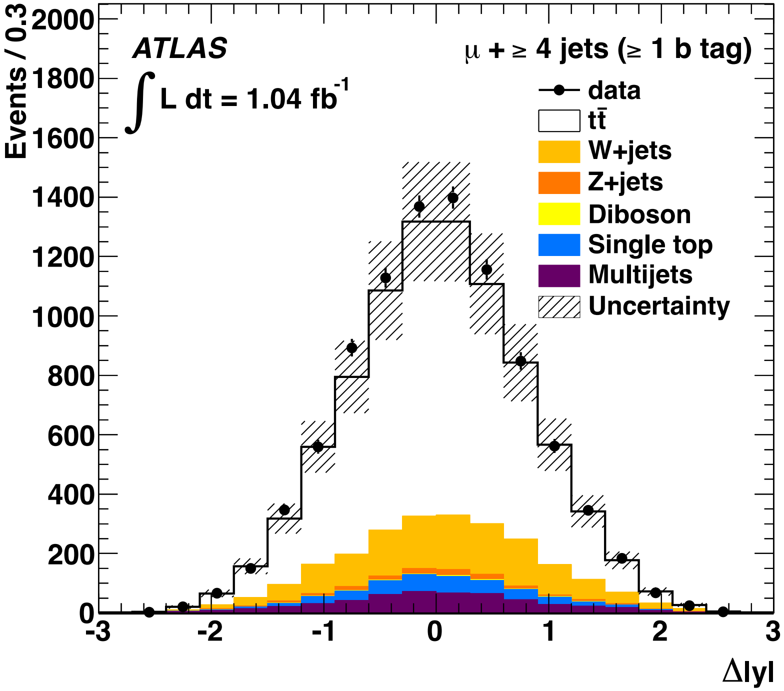
$$A_C = \frac{N(\Delta|y| > 0) - N(\Delta|y| < 0)}{N(\Delta|y| > 0) + N(\Delta|y| < 0)}$$

where $\Delta|y| = |y(t)| - |y(\bar{t})|$

A_C (theory) = 0.006 ± 0.002

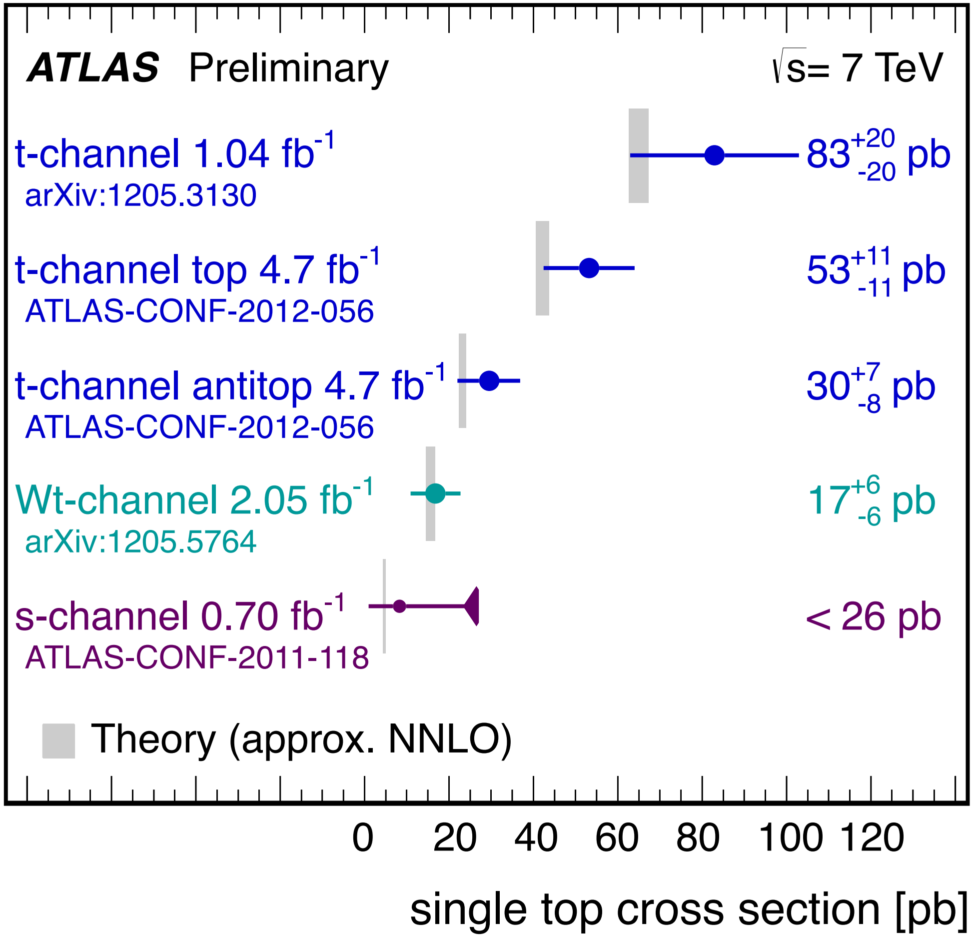
After unfolding, measure:

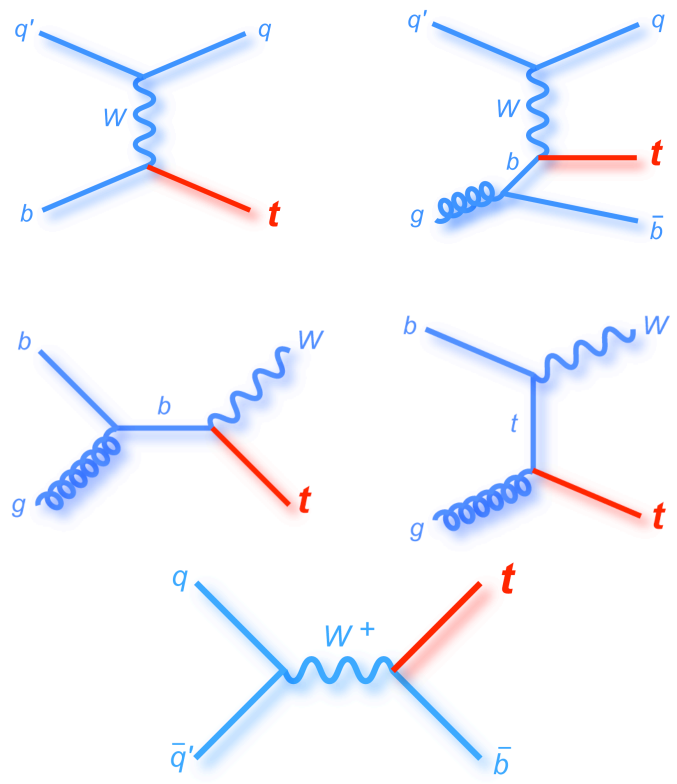
$A_C = -0.019 \pm 0.028\ (\text{stat}) \pm 0.024\ (\text{syst})$



Single top production

- Small cross sections – multivariate techniques to pick out signal





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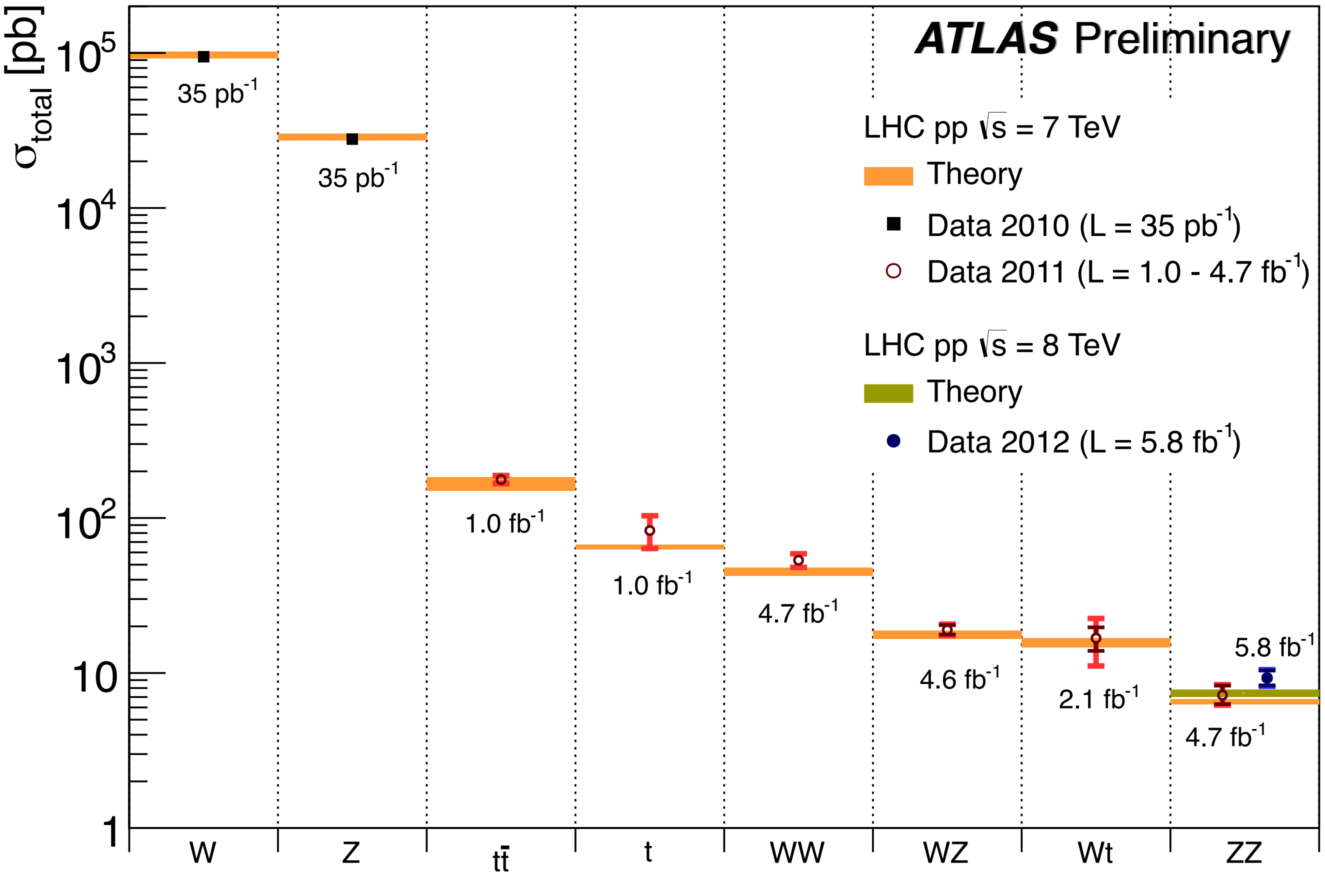
Standard Model

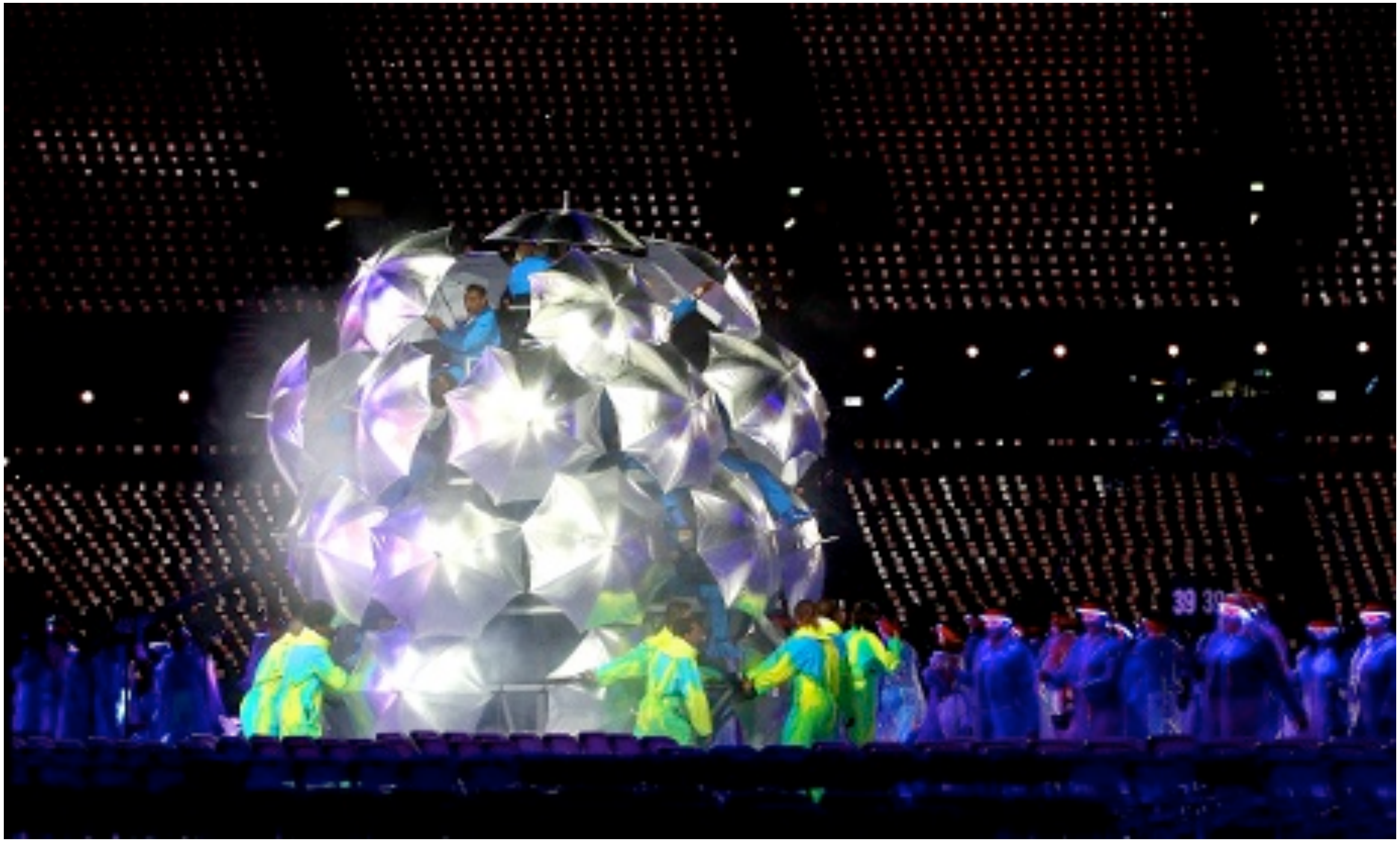
QCD studies, W, Z, diboson and top production all agree with SM expectation...



http://www.guardian.co.uk/sport/2012/aug/29/paralympics-2012-pictures

Standard Model

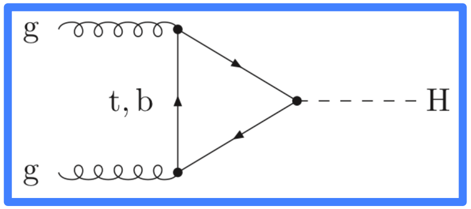
QCD studies, W, Z, diboson and top production all agree with SM expectation. Which requires at least one Higgs boson...



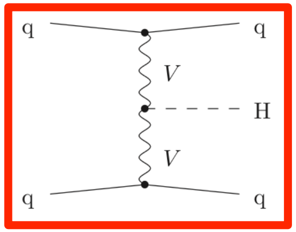
https://twiki.cern.ch/twiki/bin/view/LHCPhysics/CrossSections

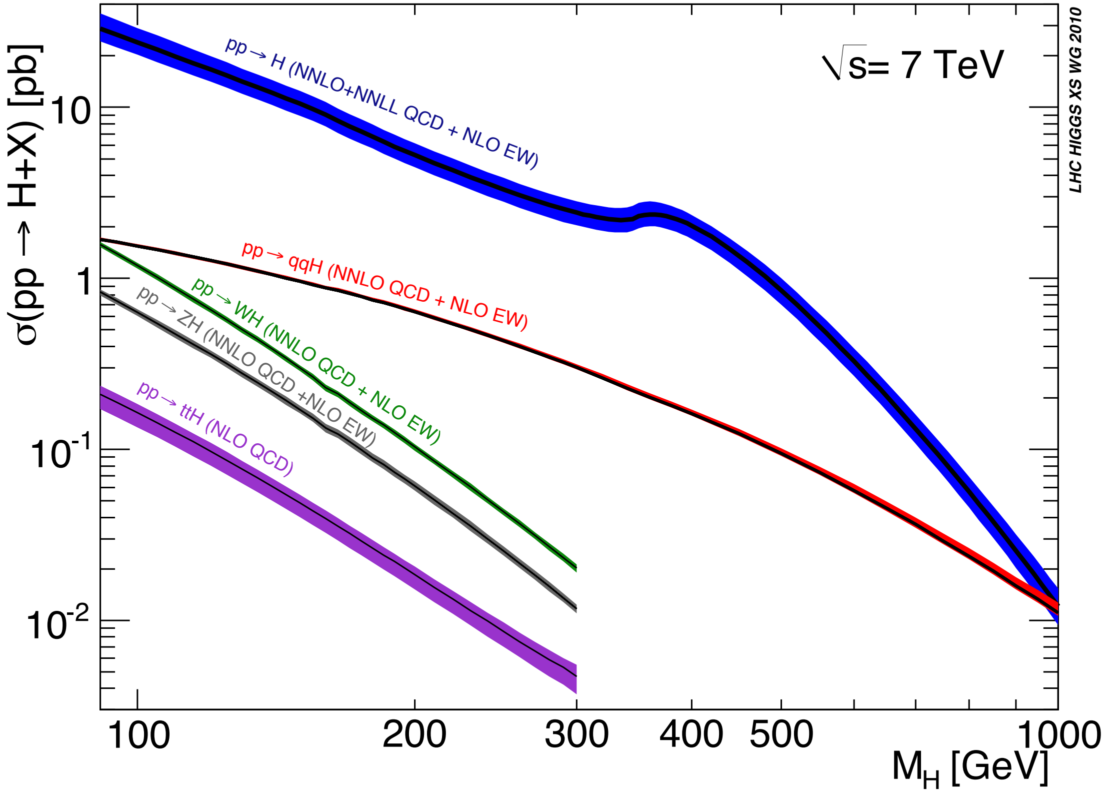
Higgs production

Gluon Fusion dominates
(note fermion loop)

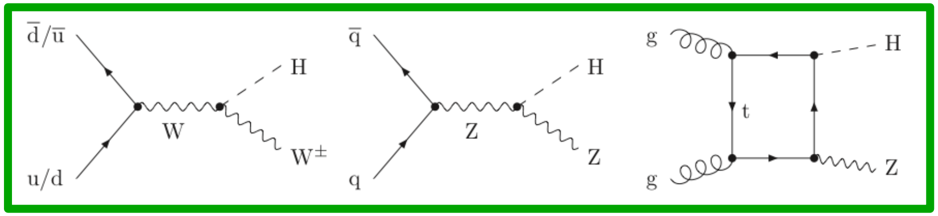


Vector Boson Fusion
(extra jets)

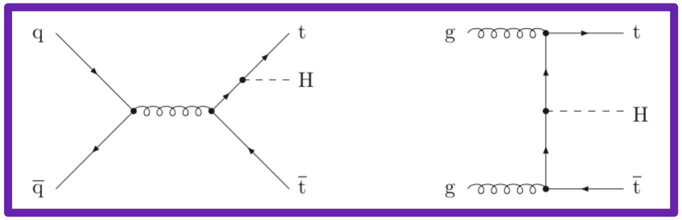




Associated production: WH,ZH...



and ttH

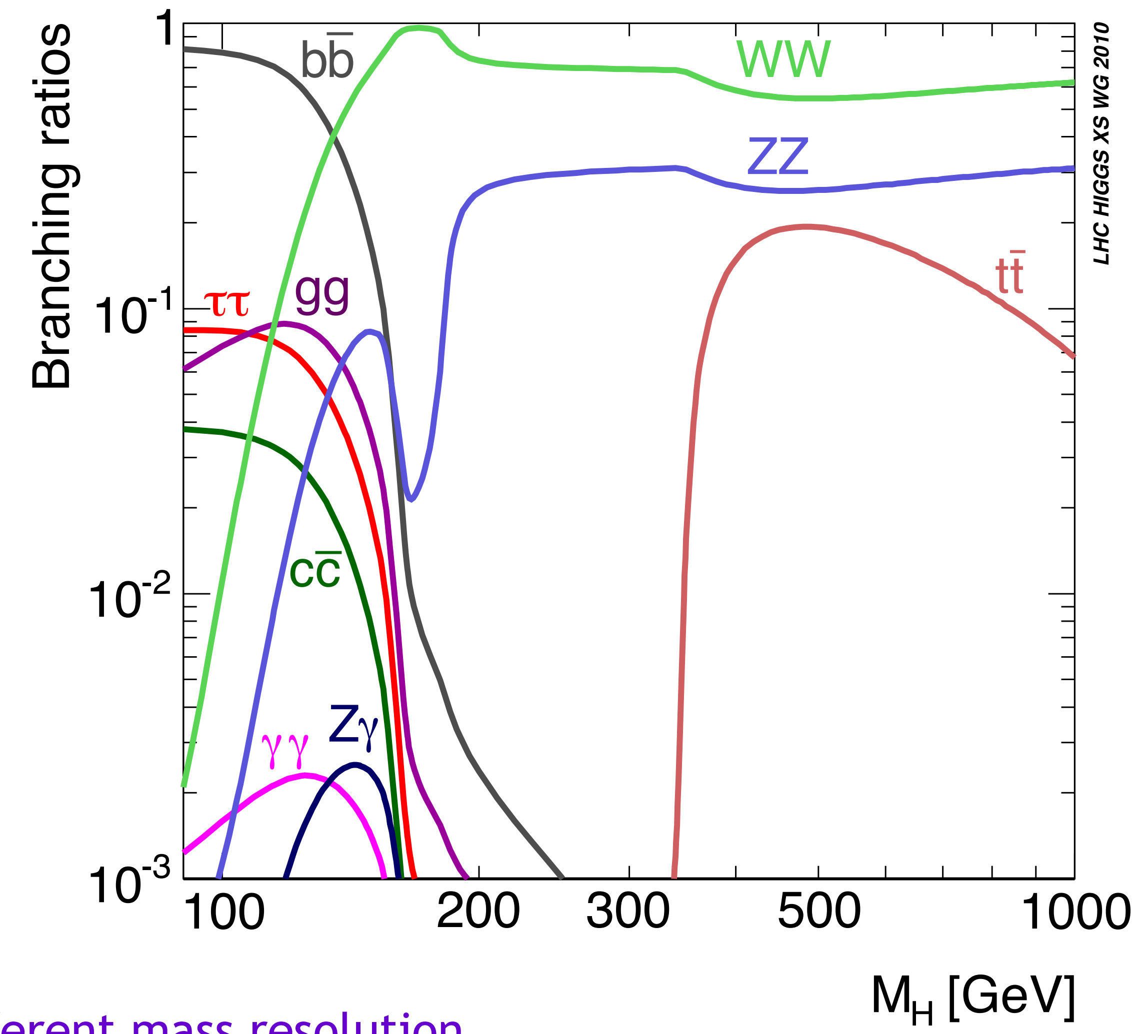


Higgs branching ratios

Useful channels for
Higgs search depend
on signal/background:

WW* and ZZ* give best
sensitivity at high mass

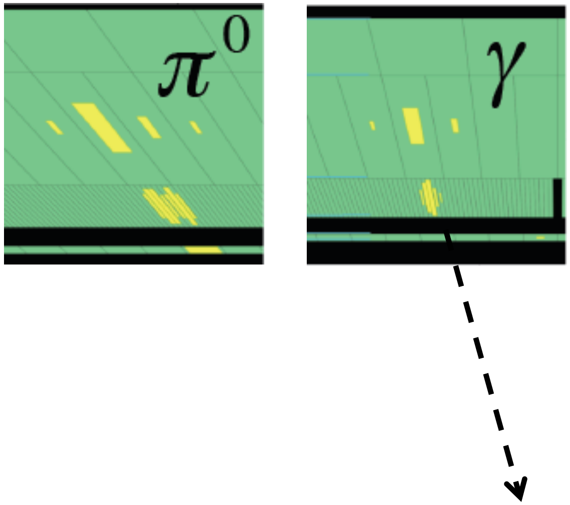
H→γγ clean channel
for low mass region
despite small BR
H→ττ also useful
H→bb can be used when
associated with W, Z, tt



Different channels have different mass resolution

$H \rightarrow \gamma\gamma$

ATLAS segmented calorimeter helps reject background and gives pointing information

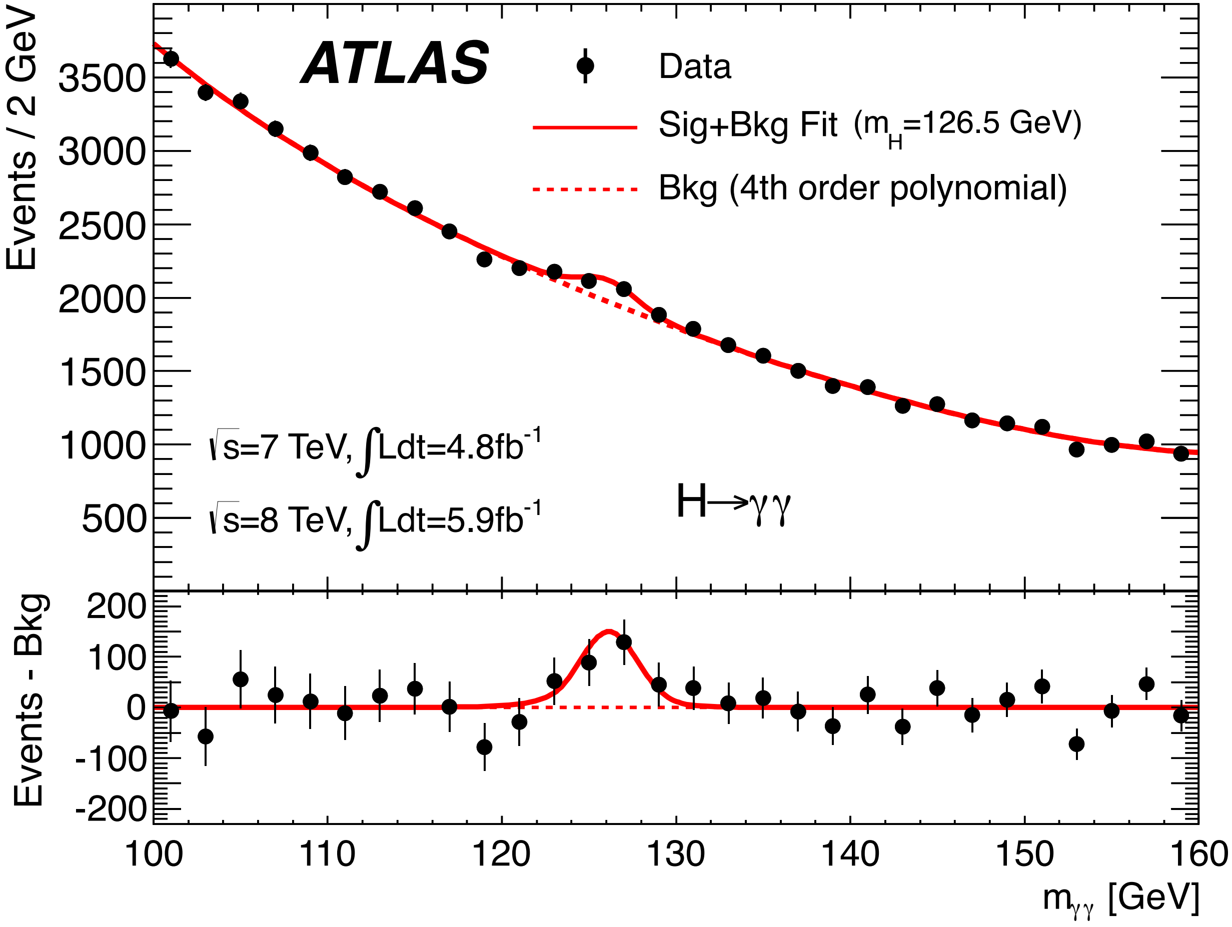


- Require rejection factors of
  - 10^4 against γ-jet
  - 10^7 against j-j
- Main background from leading π^0
  - Fake rates can be fitted from data
- Di-photon mass resolution:
  $m^2 = 2p_1p_2(1-\cos\vartheta)$
- Resolution checked with Z peak
  - Photon conversions help to give angular information
- Typical mass resolution 1.5 GeV to 2.0 GeV, depending on
  - region of the detector
  - whether the photon has converted
- Also divide up data according to
  - pT of diphoton system relative to its thrust
  - Presence of additional jets

ATLAS arXiv:1207.7214 [hep-ex]

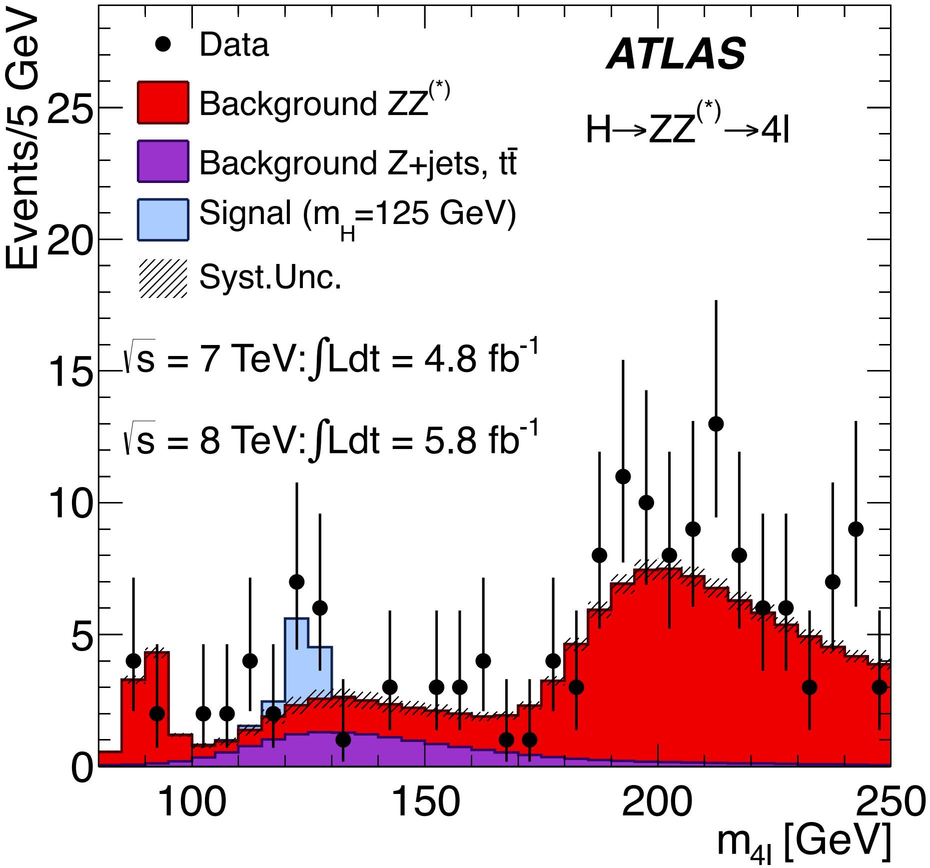
Observed diphoton mass

- In practice, analysis is performed for 10 different channels – fit signal and background in each. This is the inclusive distribution:



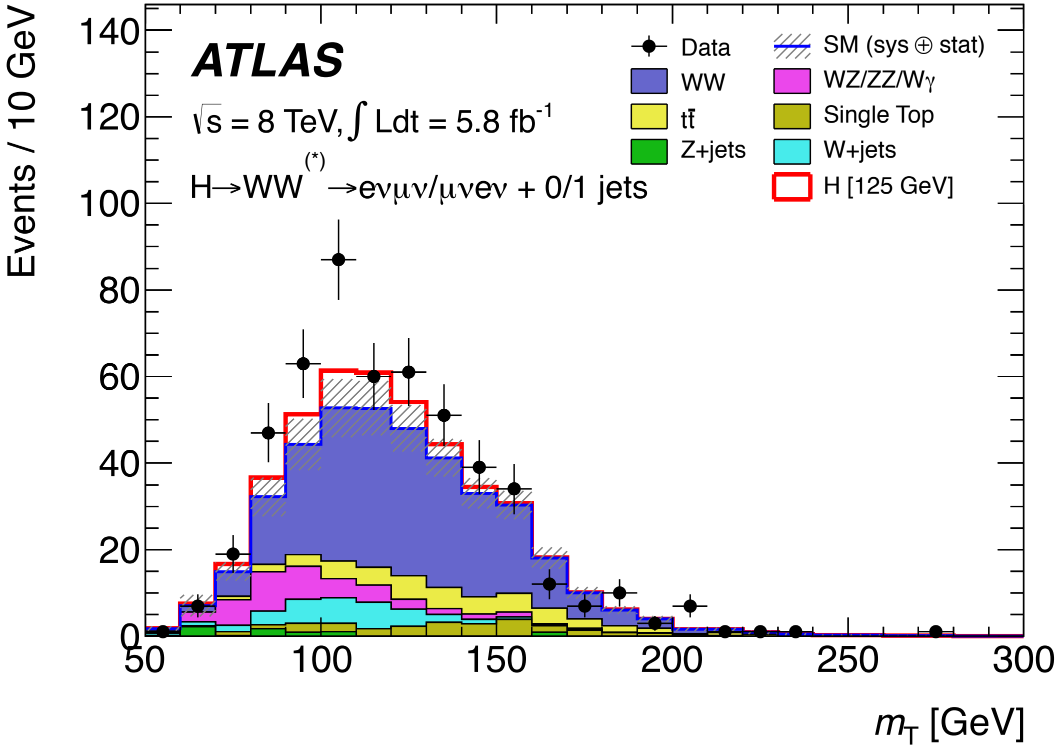
H → ZZ → llll

- Gold-standard channel. Very clean, but low rate.
  - Two isolated, same-flavour, opposite-charge lepton pairs
  - Good mass resolution from the four-lepton system.
- Four-fermion decays of the Z visible at 90 GeV
- ZZ production peaks at 200 GeV
- Excess above other SM processes at ~125 GeV



H → WW →lvlv

- Two opposite sign, isolated leptons and E_T^{miss}.
  - No mass peak, so design counting experiments optimised for each candidate mass.
  - Only use eμ channel to reduce Z background
  - Require small Δϕ between the leptons
- Construct a transverse mass variable:



ATLAS arXiv:1207.7214 [hep-ex]

Summary of channels in combination

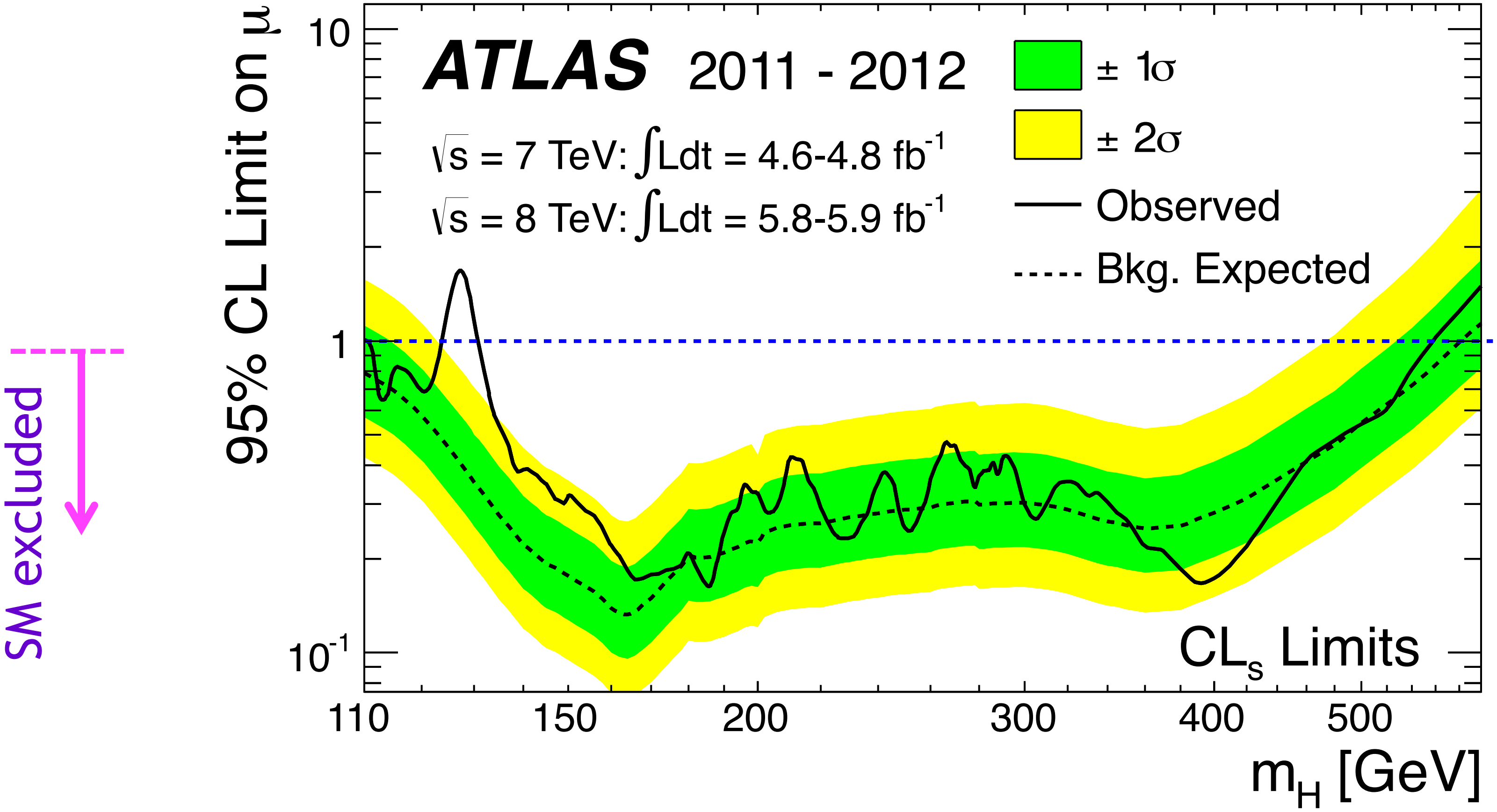
Integrated lumi and mass range:	7 TeV [fb^{-1}]	8 TeV [fb^{-1}]	m_H [GeV]
H → $\gamma\gamma$	4.8	5.9	110-150
W,Z + H → bb	4.7	---	110-130
H → $\tau\tau$	4.7	---	100-150
H → WW →lνlν	4.7	5.8 (eμ only)	110-600 (110-200)
H → WW → lνqq	4.7	---	300-600
H → ZZ → llll	4.8	5.8	110-600
H → ZZ → llqq	4.7	---	200-600
H → ZZ → llνν	4.7	---	200-600

- The channels have different signal/background & mass resolution
- Each channel is further divided into numerous sub-channels

ATLAS arXiv:1207.7214 [hep-ex]

SM Higgs exclusion

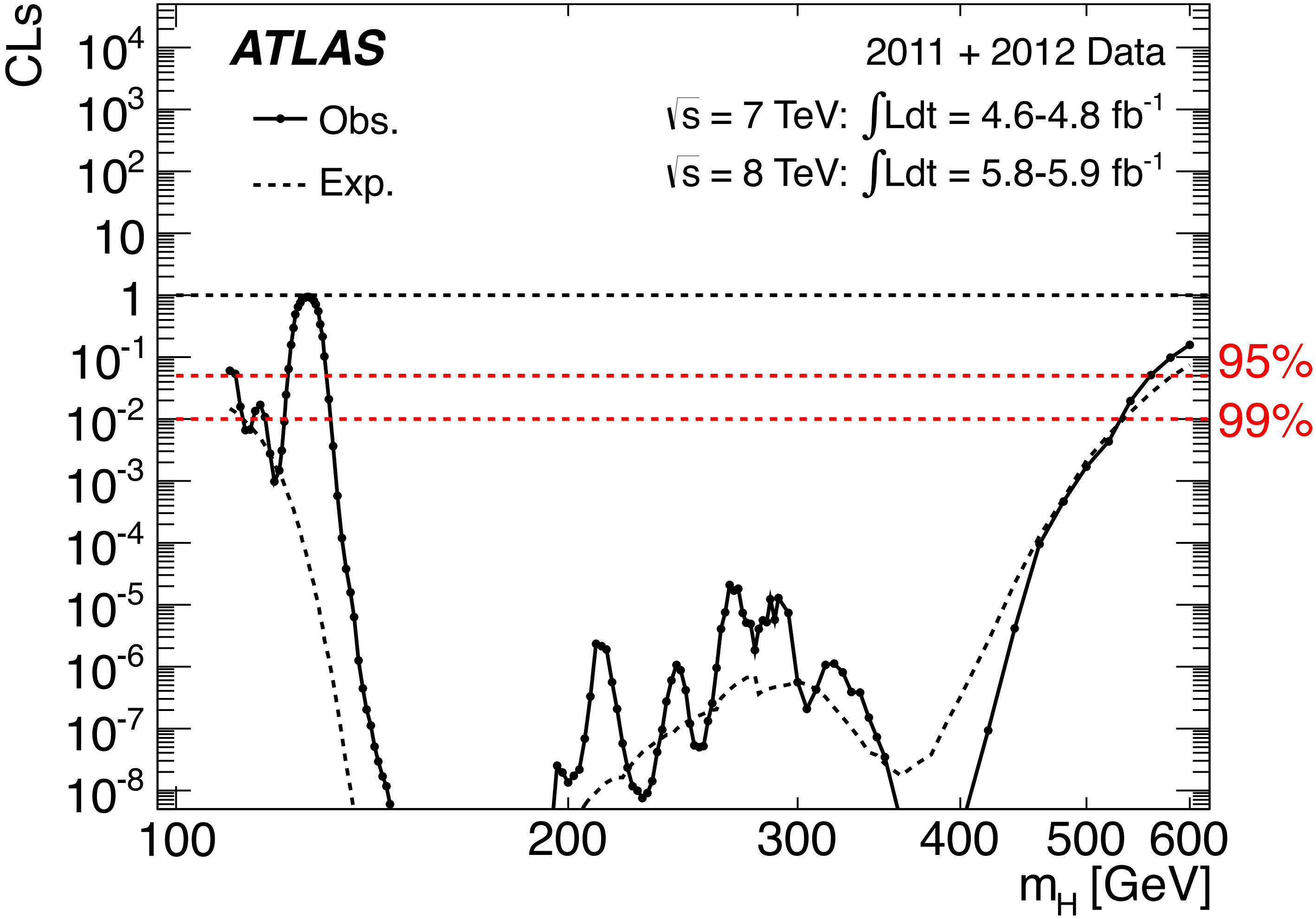
- Excluded in the ranges 111–122 GeV (extends the LEP constraint at low mass) and 131–559 GeV



ATLAS arXiv:1207.7214 [hep-ex]

Strength of exclusion of SM cross section

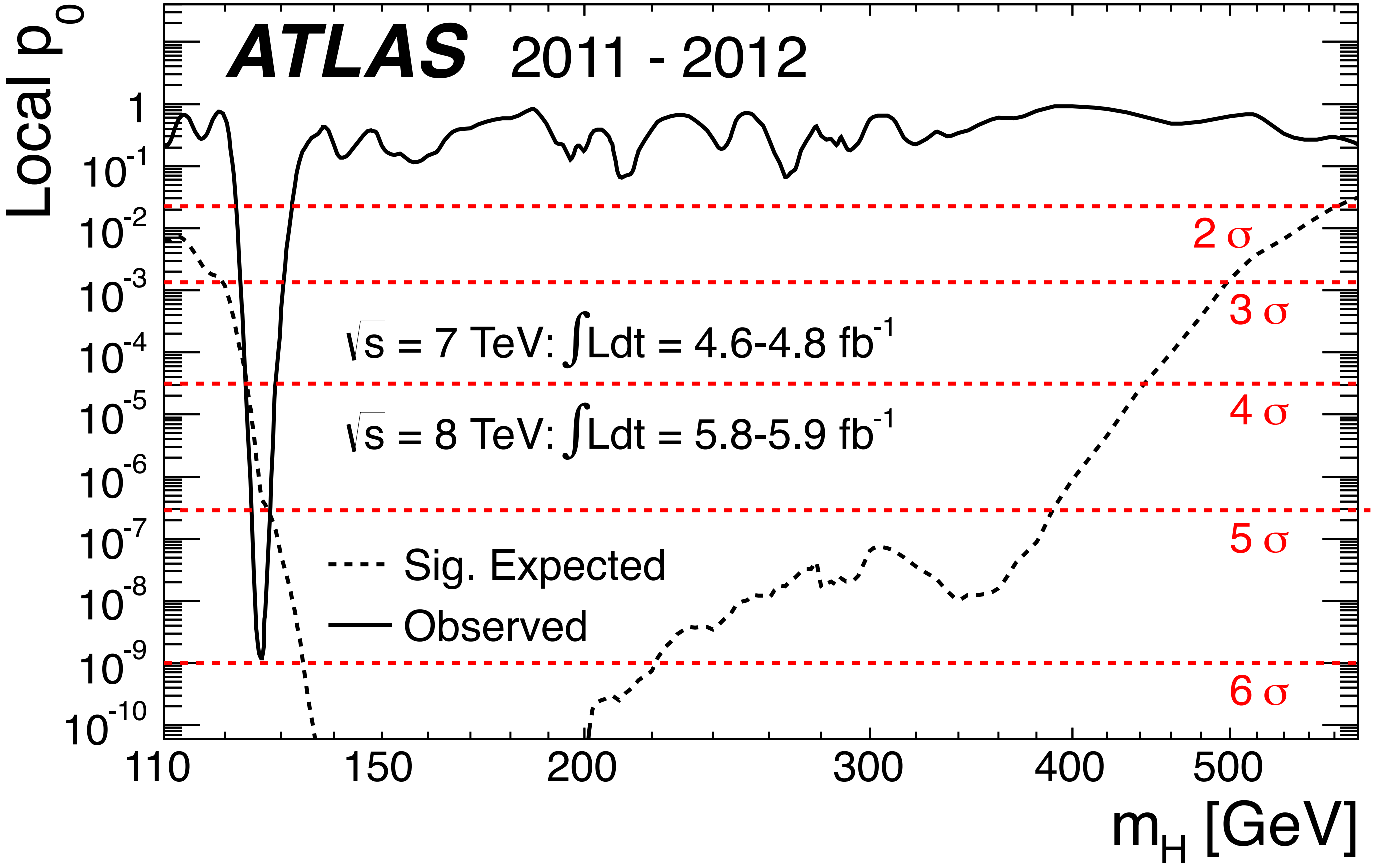
- Expexcted limit is shown for background only (no Higgs) hypothesis



ATLAS arXiv:1207.7214 [hep-ex]

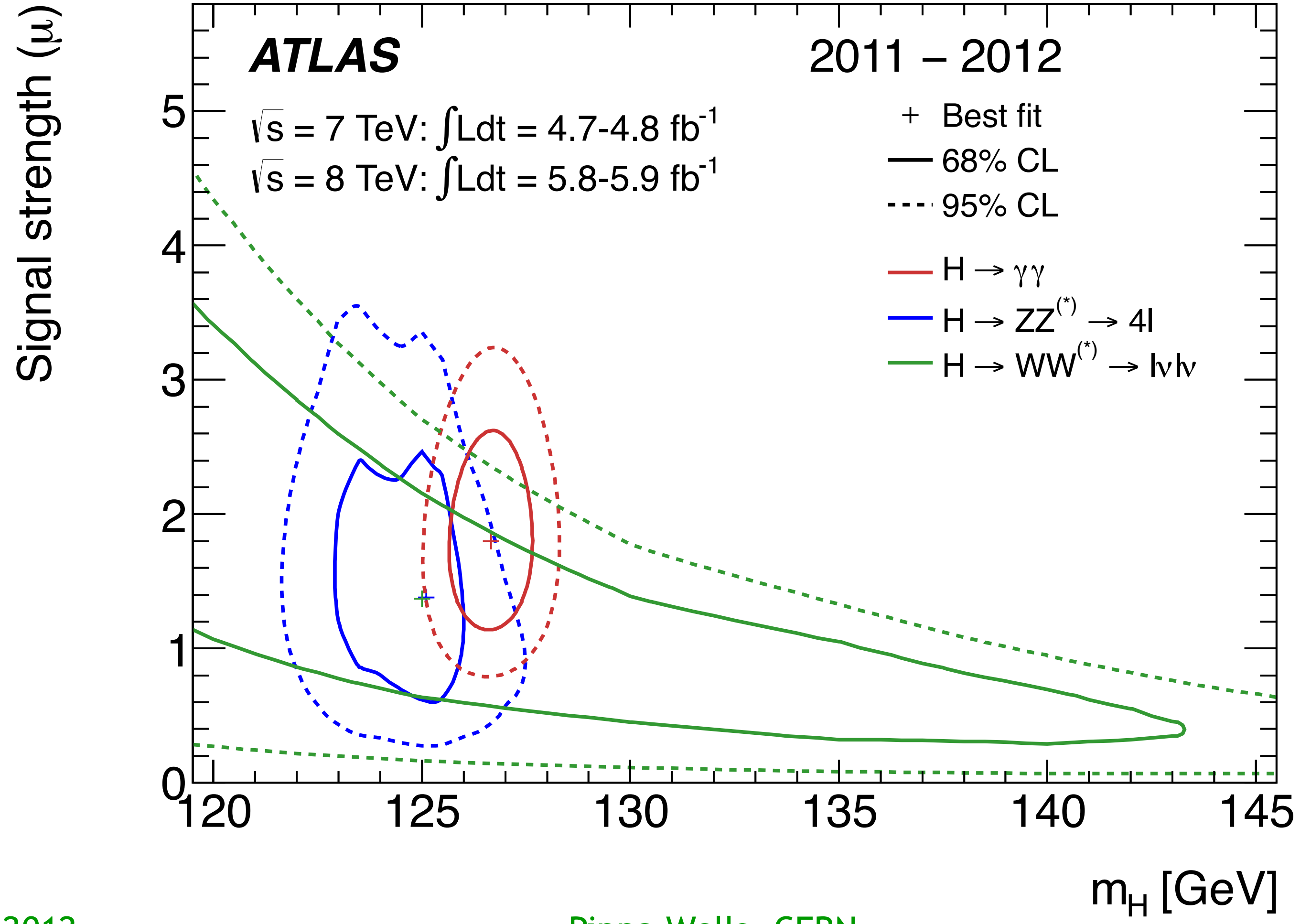
Consistency with background

- Compare the *local* p-value at each mass to estimate consistency with the background-only hypothesis: minimum corresponds to 5.9 σ excess
    - "Expected" dashed line shows the median expected significance in the hypothesis of SM Higgs boson production at each m_H



Mass of the new boson

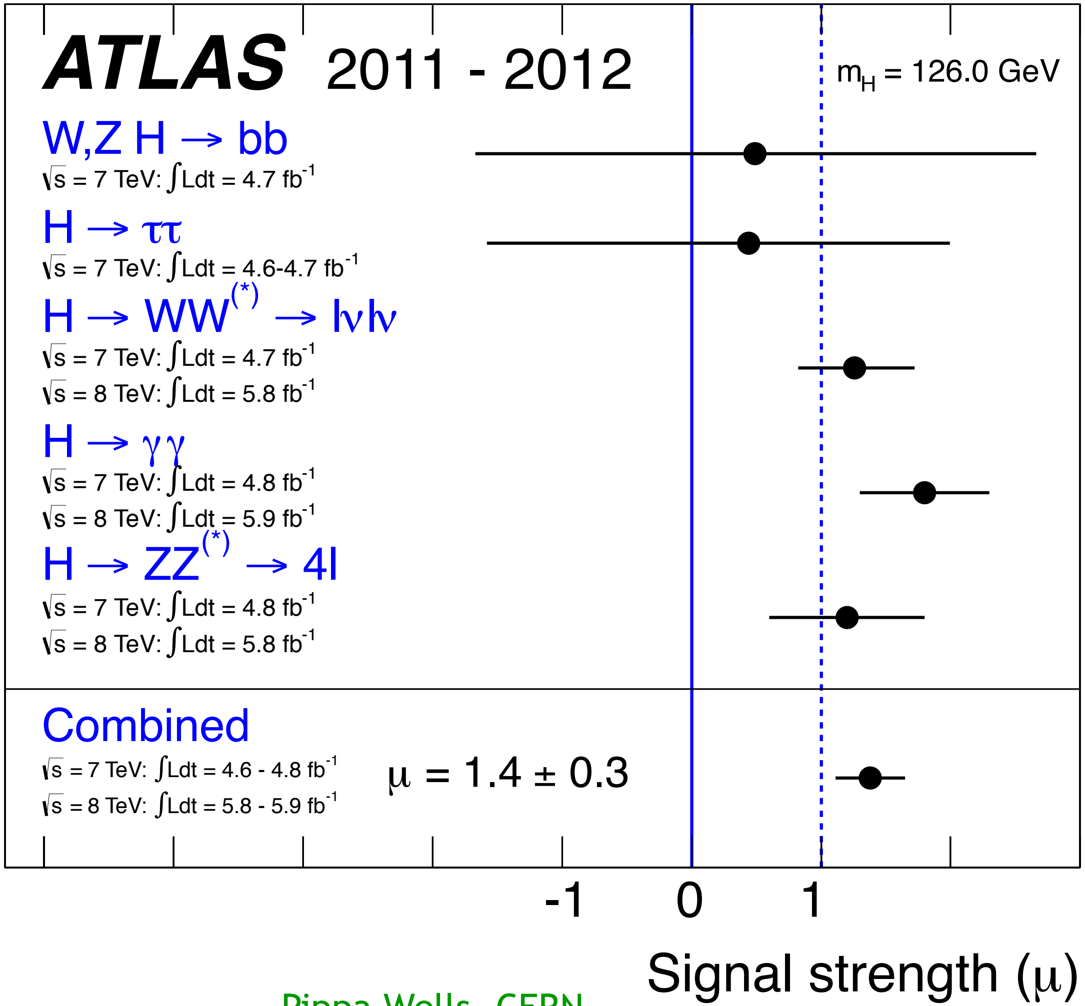
- Combine masses from γγ and ZZ→4l channels without constraining signal strength: Mass = 126.0 ± 0.4 ± 0.4 GeV



ATLAS arXiv:1207.7214 [hep-ex]

Signal strength in each channel

- New boson is consistent with SM Higgs ($\mu = \sigma / \sigma_{SM}$)
- Measurements have been interpreted in terms of couplings

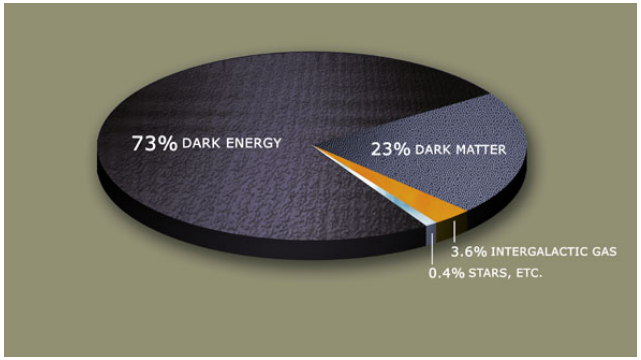


Non-standard Higgs

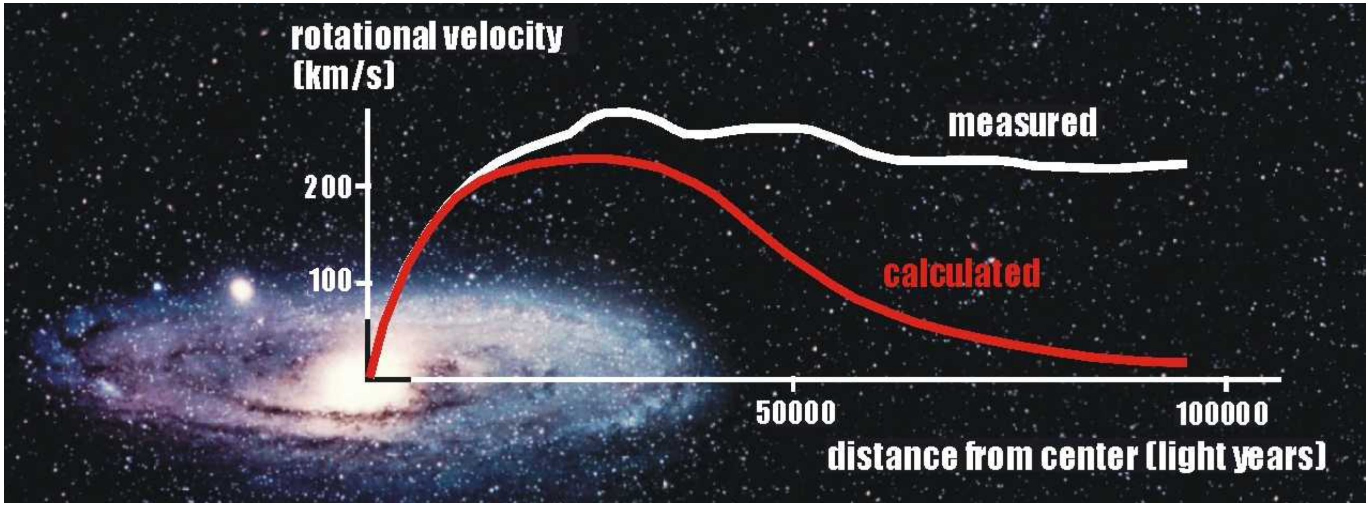
- A single Standard Model Higgs is the minimal solution
  - Two Higgs doublet models (eg. type-II 2HDM as needed for supersymmetry) have:
    3 neutral: light h, heavy H (CP even) and A (CP odd)
    2 charged: H^+, H^-
- Continue to look for other Higgs-like charged and neutral bosons, as well as measuring the properties of the new boson as carefully as possible

Beyond the Standard Model

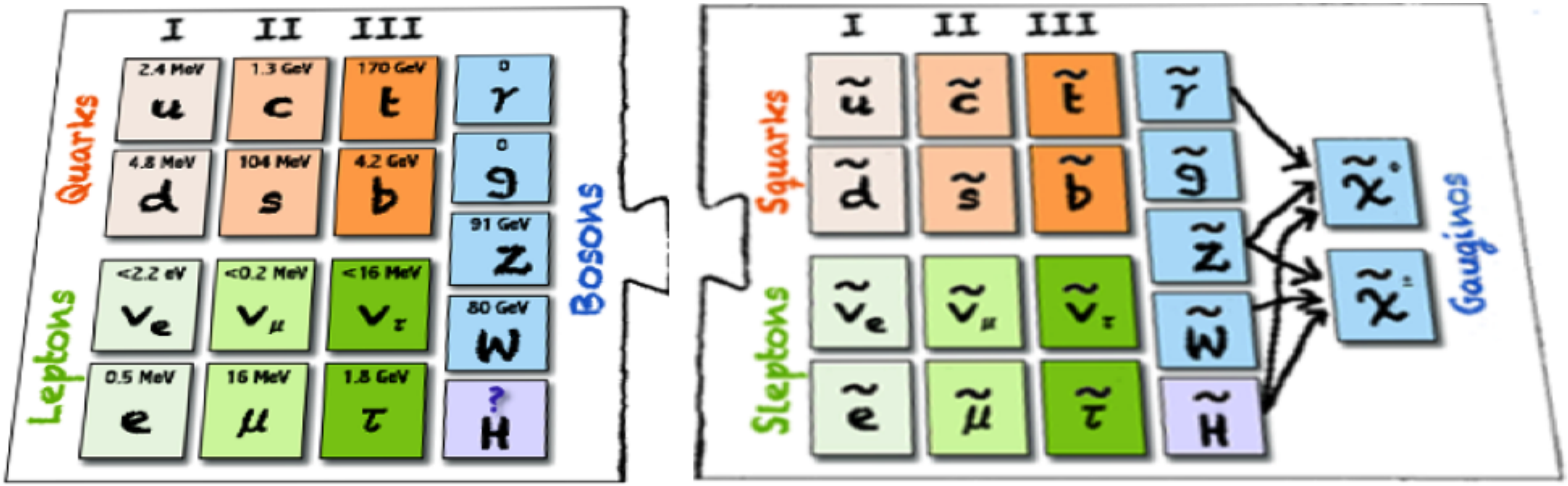
- The Standard must be extended by a more complete theory at high energies to explain:
  - Gravity
  - Dark Matter
  - Dark Energy
  - Matter / Anti-matter asymmetry
  - Hierarchy, naturalness, fine tuning...



eg. galactic rotation curves need extra dark matter



SUSY



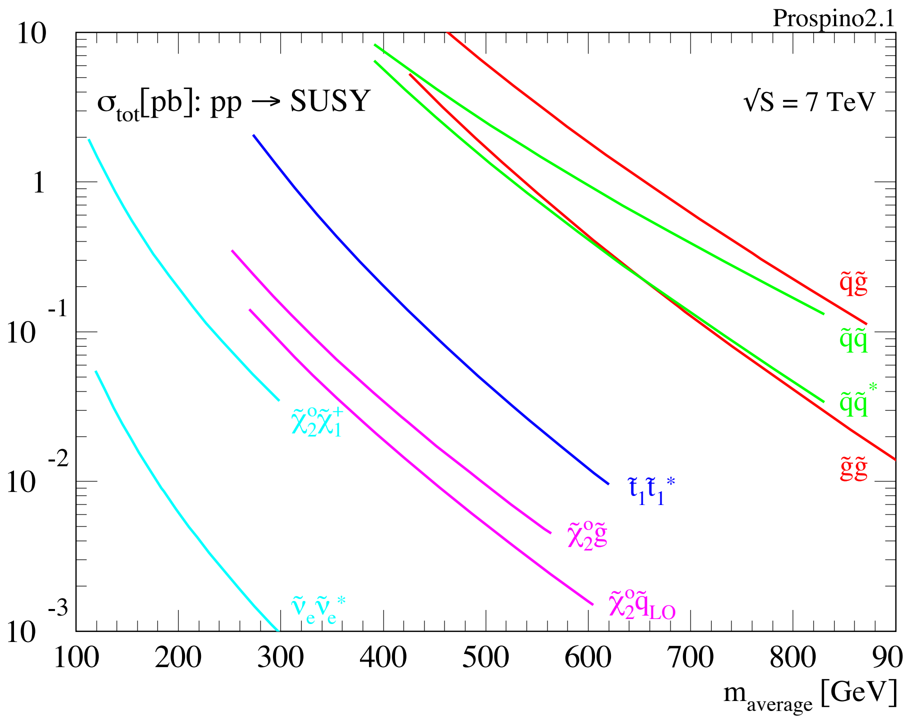
- Standard model particles have supersymmetric partners with ½ unit different spin
- No SUSY particles have been observed – broken symmetry
- Conserved quantum number R-parity: +1 for SM, -1 for SUSY particles. (Preserves baryon and lepton number conservation).
  - SUSY particles are produced in pairs
  - Lightest SUSY partner (LSP) stable → dark matter candidate. (Charge and colour neutral to be viable candidate.)

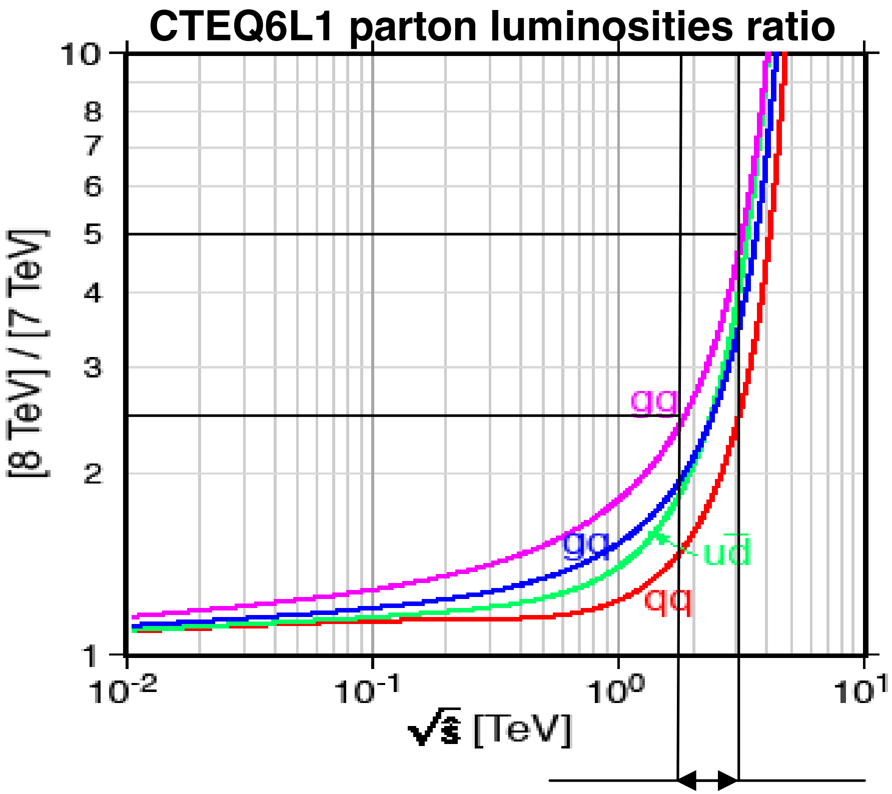
MSSM, CMSSM and simplified models

- Minimal supersymmetric standard model, MSSM, requires two Higgs doublets and all the superpartners.
  - → 124 independent free parameters
- Constrained minimal extension of the Standard Model has only five parameters (at high, GUT scale)
  - Universal scalar mass m_0
  - Universal gaugino mass $m_{1/2}$
  - Universal trilinear soft SUSY breaking A_0
  - Ratio of vacuum expectation values of two Higgs doublets, $\tan \beta$
  - Sign of the Higgs mixing parameter, $\mathrm{sign}(\mu)$
- CMSSM is convenient for interpreting the results of searches for SUSY particles
- Simplified models – give cross-section limits or excluded mass regions as a function of eg. squark and gluino mass.
  - Phenomenology depends on mass splittings between squark/gluino, LSP and standard model particles

SUSY production cross-sections at LHC

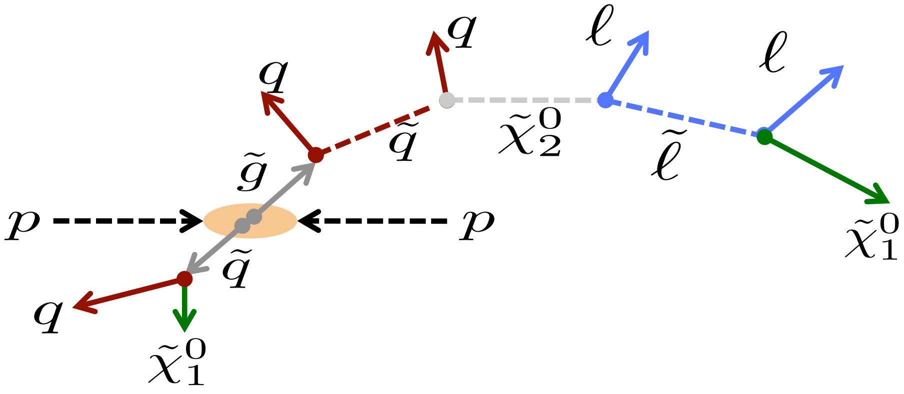
- Cross sections [pb] as a function of mass
  - Logarithmic dependence → gain with increasing luminosity
- At energy frontier, can gain factor 2~5 in parton luminosity from increase in centre-of-mass from 7 to 8 TeV





2 M_{SUSY} = 1.6 3.2

Search strategies



- Very rich phenomenology:
  - Short/long decay chains
  - Maybe with leptons
  - Maybe with different lepton & jet flavours
  - Often large E_T^{miss} (MET)
- Divide analyses according to observable topologies
- Then interpret the results in specific SUSY models
- Highlight here new results using 8 TeV data sample

- R-parity conserving searches:
  - 0-lepton
  - 1-lepton
  - 2-leptons
  - b-jets
  - photons
  - long-lived hadrons
- Also RPV models

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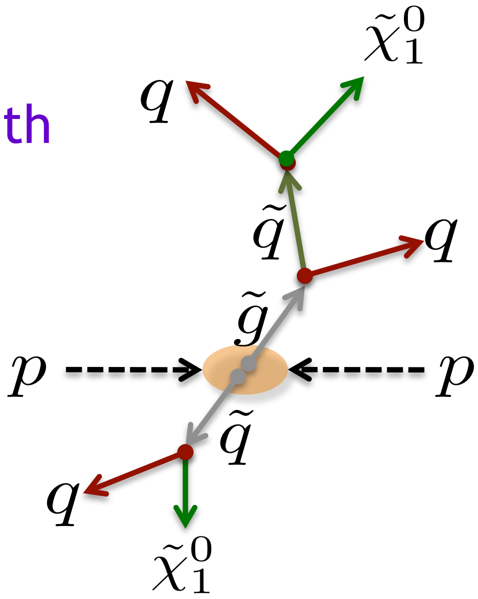
ATLAS jets and MET search



- Optimised for discovery in simplified model with
  - low mass LSP
  - observable squarks (1st and 2nd generations) and gluinos
  - all other SUSY particles high mass
  - short decay chains.
- Trigger on jets and MET.
- Veto events with leptons.
- Signal regions according to number of jets and value of m_{eff}:

$$m_{\text{eff}} = \sum_i \left| \vec{p}_T^{\,\text{jet},i} \right| + E_T^{\text{miss}}$$

- 4 control regions for each signal region to control Z→νν + jets, W + jets, top, multijets
  - Transfer functions (MC or jet smearing for multijets) to infer background in signal region
  - Combined likelihood fit to CRs and SR to normalise background

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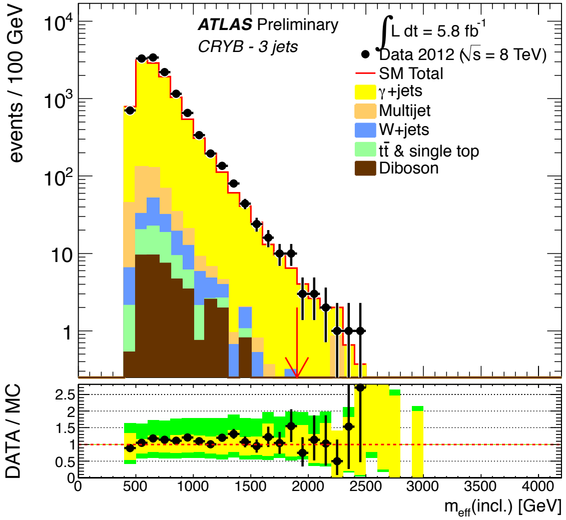
N-jet signal regions (tight/med/loose)

Requirement	2-jets	3-jets	4-jets	5-jets	6-jets
E_T^{miss} [GeV] >	160				
p_T jet 1 [GeV] >	130				
p_T jet 2 [GeV] >	60				
p_T jet 3 [GeV] >	–	60	60	60	60
p_T jet 4 [GeV] >	–	–	60	60	60
p_T jet 5 [GeV] >	–	–	–	60	60
p_T jet 6 [GeV] >	–	–	–	–	60
$\Delta\phi(j, E_T^{miss})$ [rad]	0.4 (j ≤ 3)		0.4 (j ≤ 3), 0.2 (p_T > 40GeV jets)		
$E_T^{miss}/m_{eff}^{Njet}$ >	0.3 / 0.4 / 0.4	0.25/0.3/–	0.25/0.3/0.3	0.15	0.15/0.25/0.3
$m_{eff}^{incl.}$ [GeV] >	1900/1300/1000	1900/1300/–	1900/1300/1000	1700/–/–	1400/1300/1000
Background (tight)	14 ± 5	8.7 ± 3.4	2.8 ± 1.2	6.3 ± 2.1	10 ± 4
Data (tight)	10	7	1	5	9

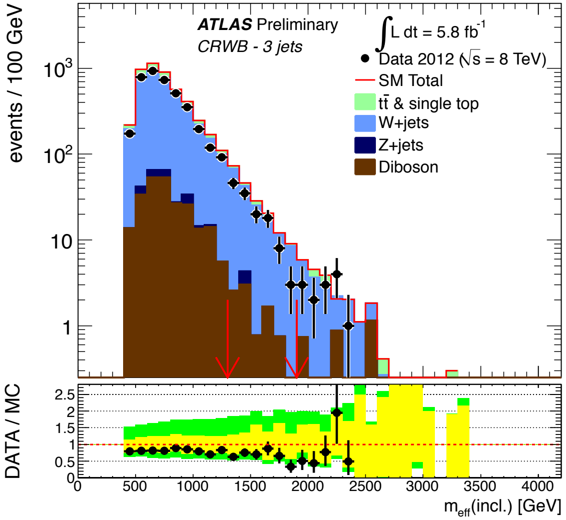
- Cuts optimised for 8 TeV centre-of-mass
- $\Delta\phi$ cut against jets aligned with MET direction and MET/m_{eff} cut are to reject QCD multijet background
- Tight cuts give max reach for high mass squark/gluino, low mass LSP
- Medium/loose cuts add sensitivity for compressed spectra
- No significant excess observed in any channel

Control and signal regions for 3-jet “tight”

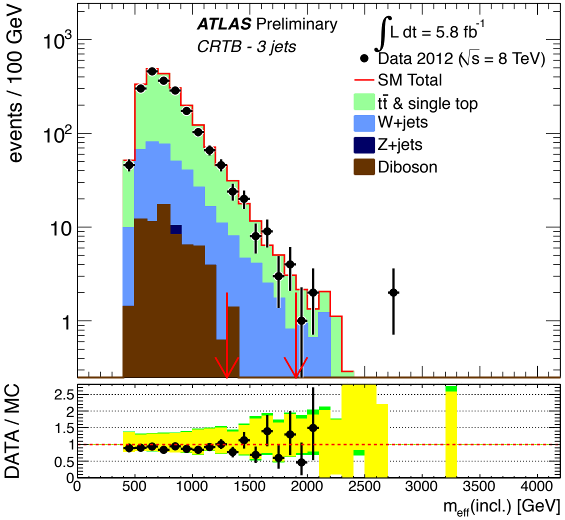
Z→νν + jets from γ+jets



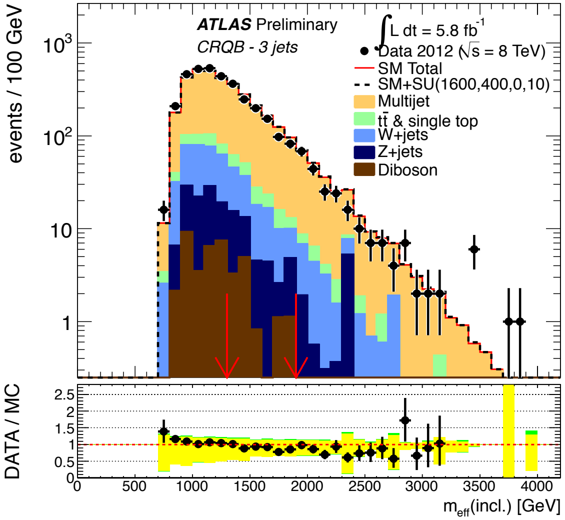
W+jets from l+MET+ jets (no b)



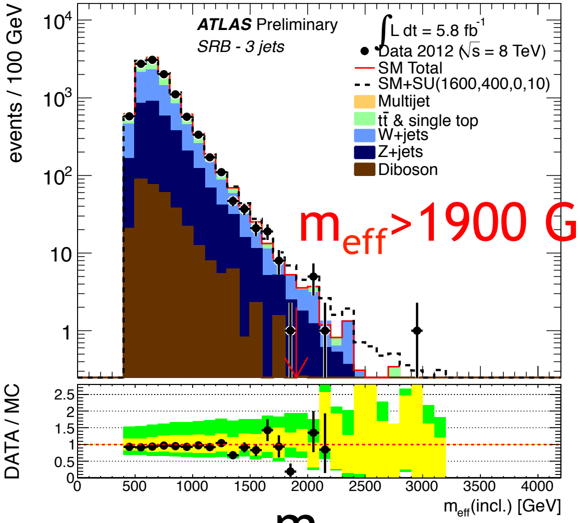
Top from l+MET+jets (btag)



QCD multijets from reversed Δφ and E_T^{miss}/m_{eff} cuts



Signal region



$m_{eff}>1900$ GeV

m_{eff}

Jets+MET results

- Exclusions in the squark-gluino mass plane for a simplified SUSY model

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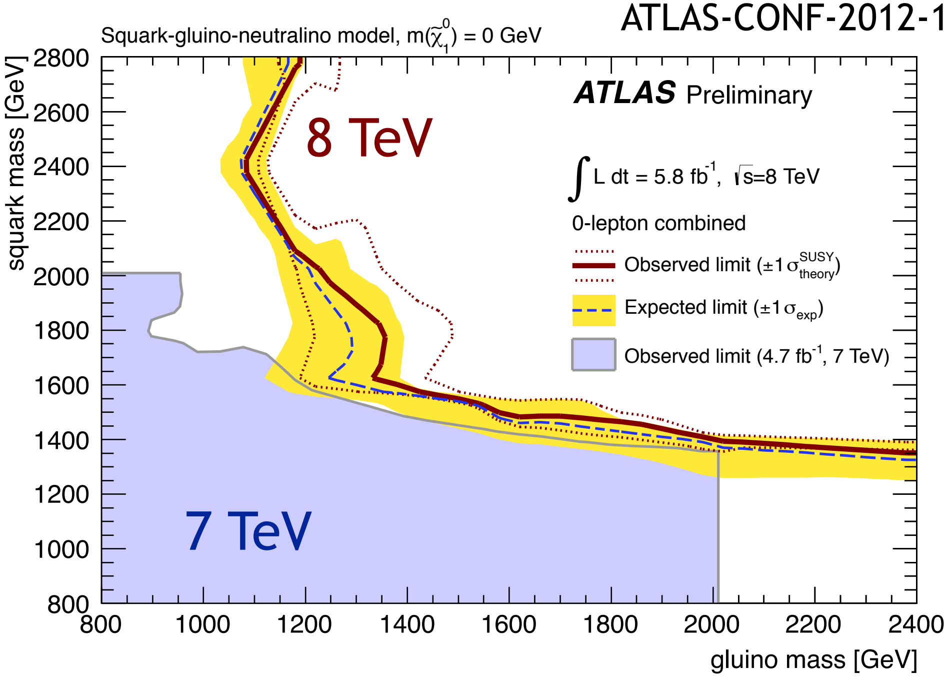
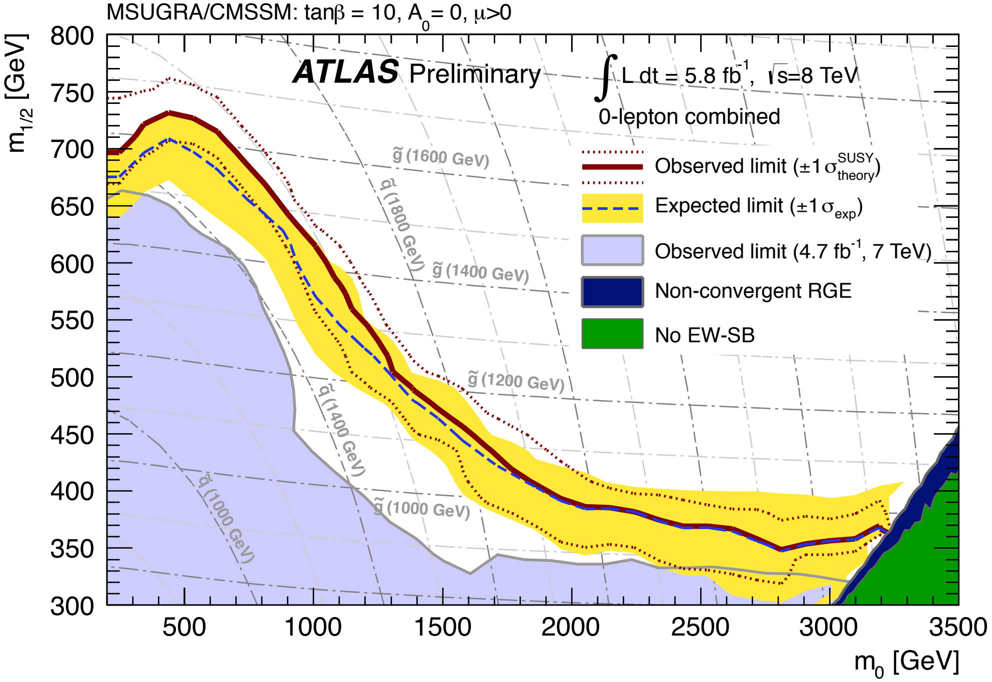


Limits stable up to ~200 GeV mass LSP



- CMSSM ($m_{1/2}$, m_0) plane: equal mass squarks and gluinos excluded below 1500 GeV

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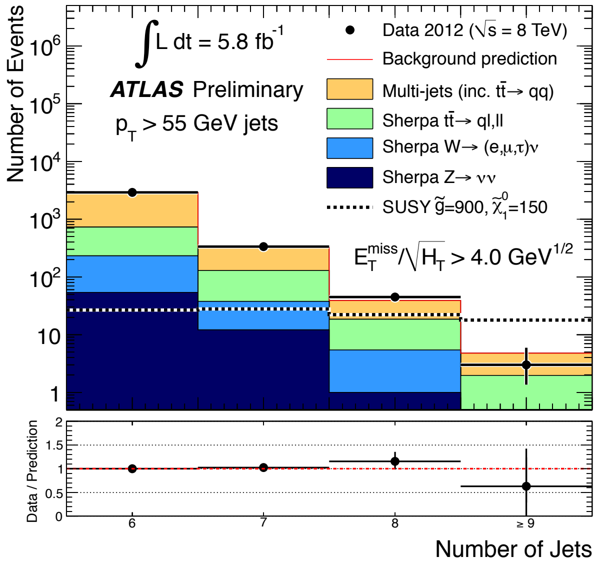
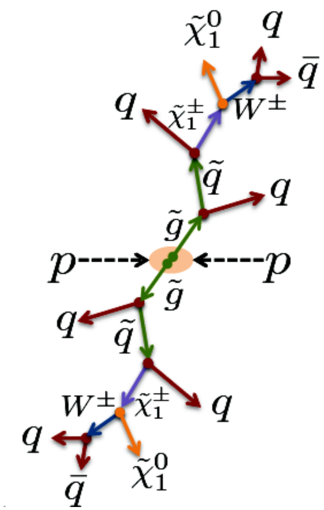
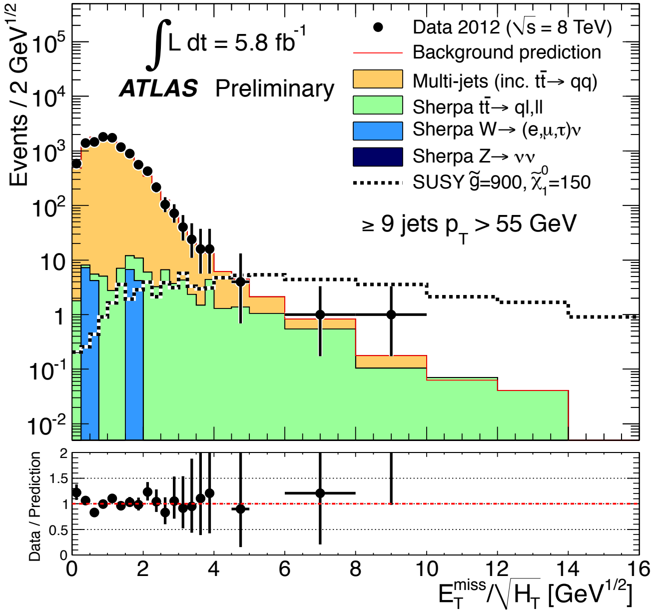
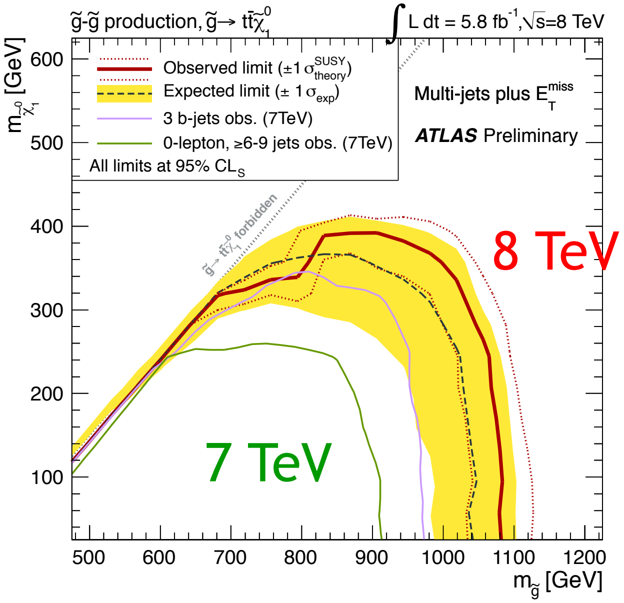
ATLAS multijet analysis

- Optimised for long decay chains
    - Require 6 to 9 jets
- Examine $E_T^{miss}/\sqrt{H_T}$; $H_T = \sum_i \left|\vec{p}_T^{\,jet,i}\right|$
- Interpretation in simplified model
    - Exclude gluino mass > 1 TeV for LSP mass <300 GeV





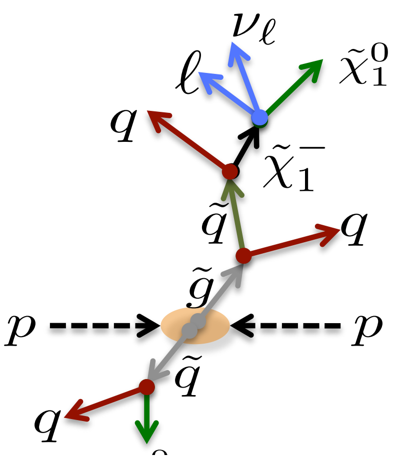


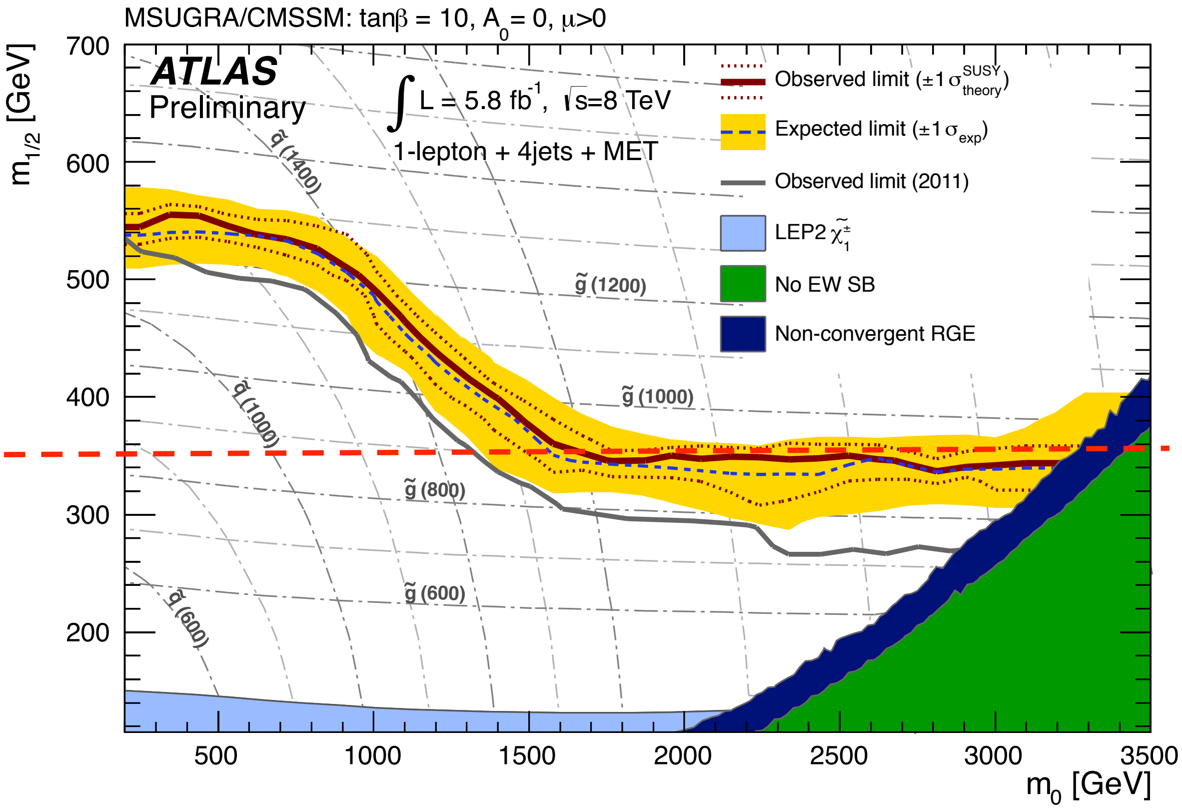


ATLAS arXiv:1109.6606 [hep-ex]

1 lepton search

- High p_T lepton from chargino or slepton decay
  - Trigger on lepton
  - Reduced QCD background → relax cuts
- Competitive with 0-lepton for high m_0 in CMSSM

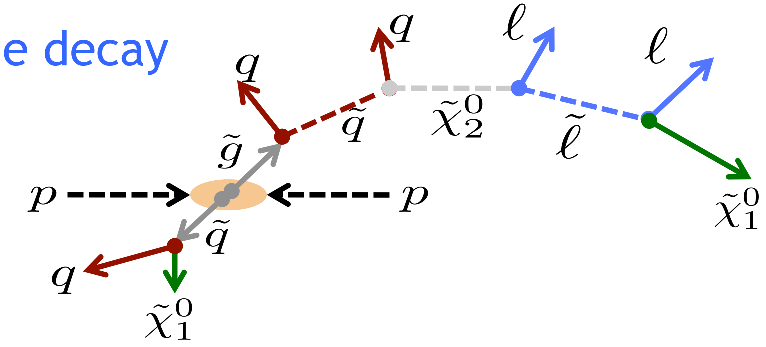


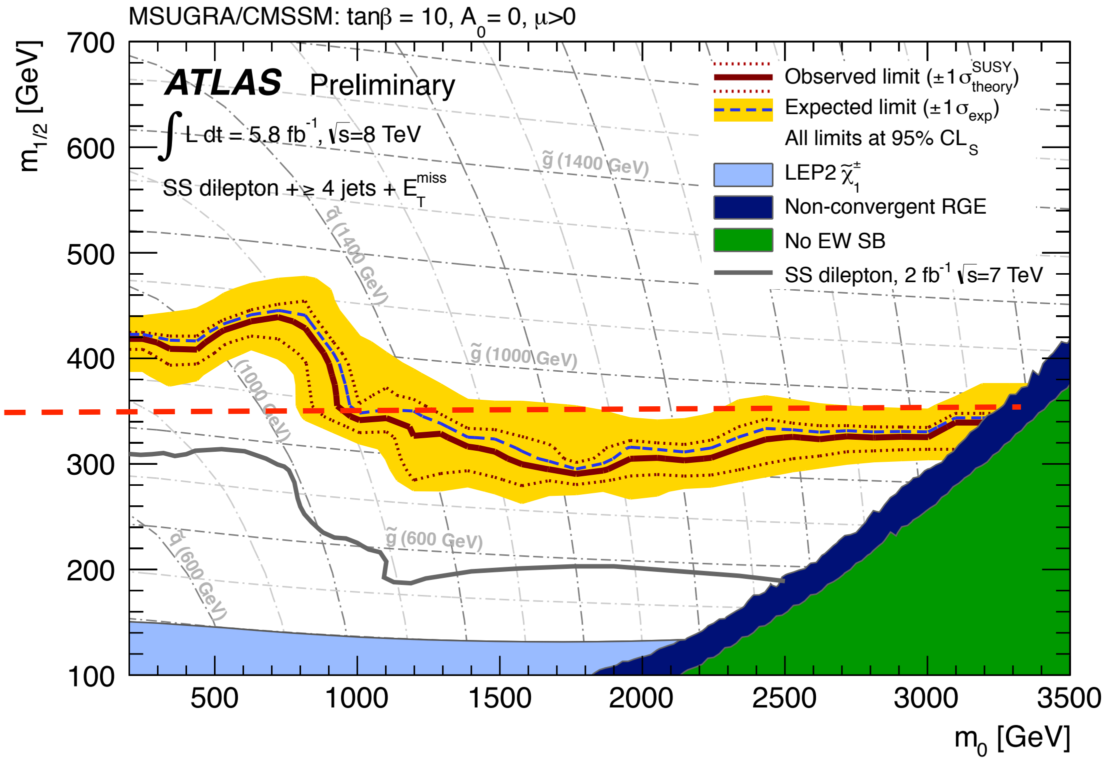


0 lepton

2 lepton final states

- Dilepton production can be from cascade decay or directly from weak pair-production
- Exploit different configurations
  - Opposite sign: OS or same sign: SS
  - “Opposite” flavour (e, μ): OF or same flavour: SF
- eg. Z decay gives OSSF



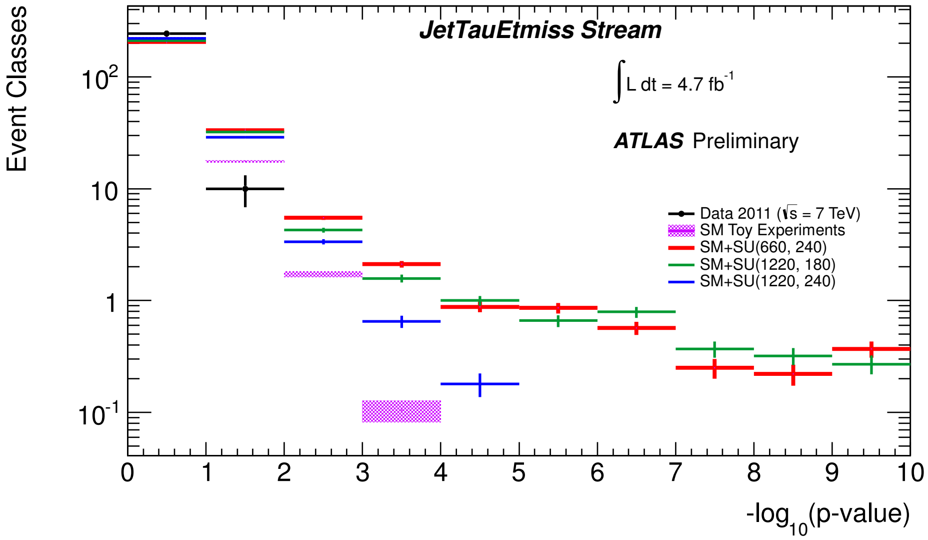


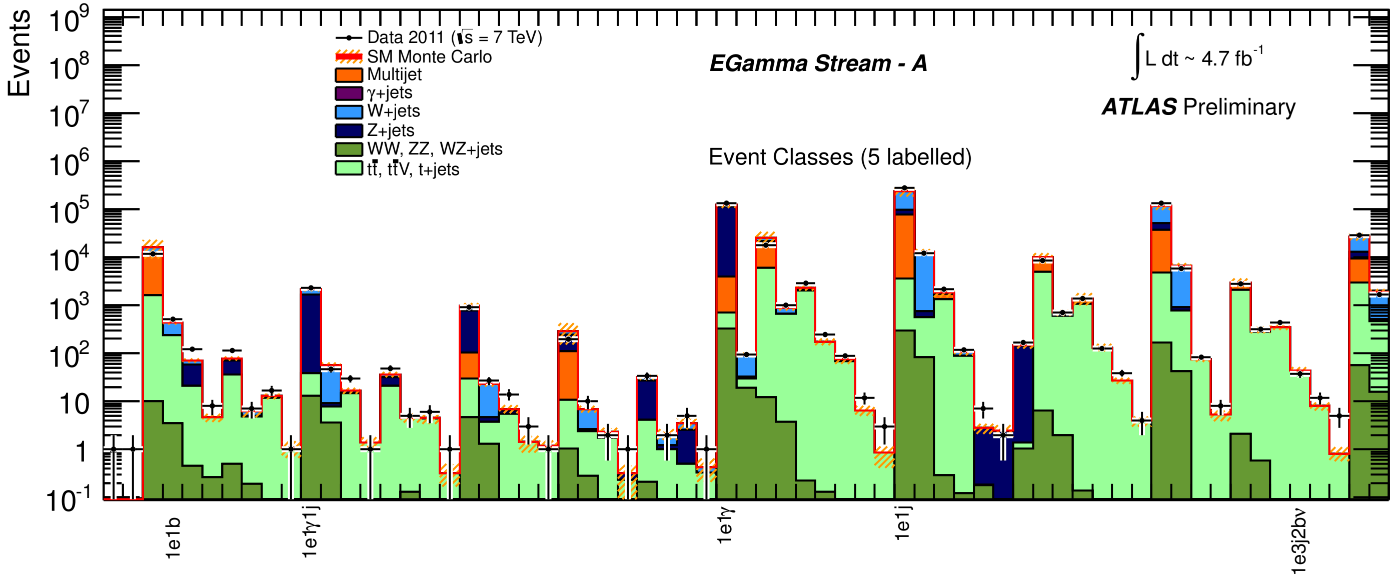
0 lepton

ATLAS-CONF-2012-107

Generalised search

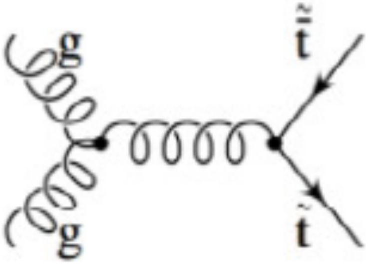
- Define event topologies according to the number of e, γ, μ, jets, b-jets, E_T^{miss} → 655 exclusive channels
- Test compatibility of m_{eff} distribution with SM processes (7 TeV data)
- Less sensitive for a specific model, but comprehensive

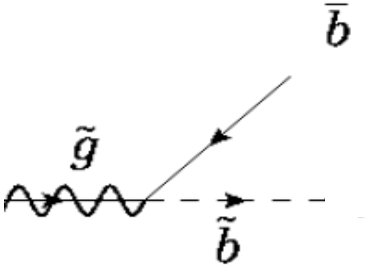




3rd generation stop/sbottom

- Mixing in the third generation can lead to light $\tilde{t}_1, \tilde{b}_1, \tilde{\tau}_1$
  - Similar stop and top masses
    favoured by naturalness arguments
- Direct pair production or via gluino decay, eg:



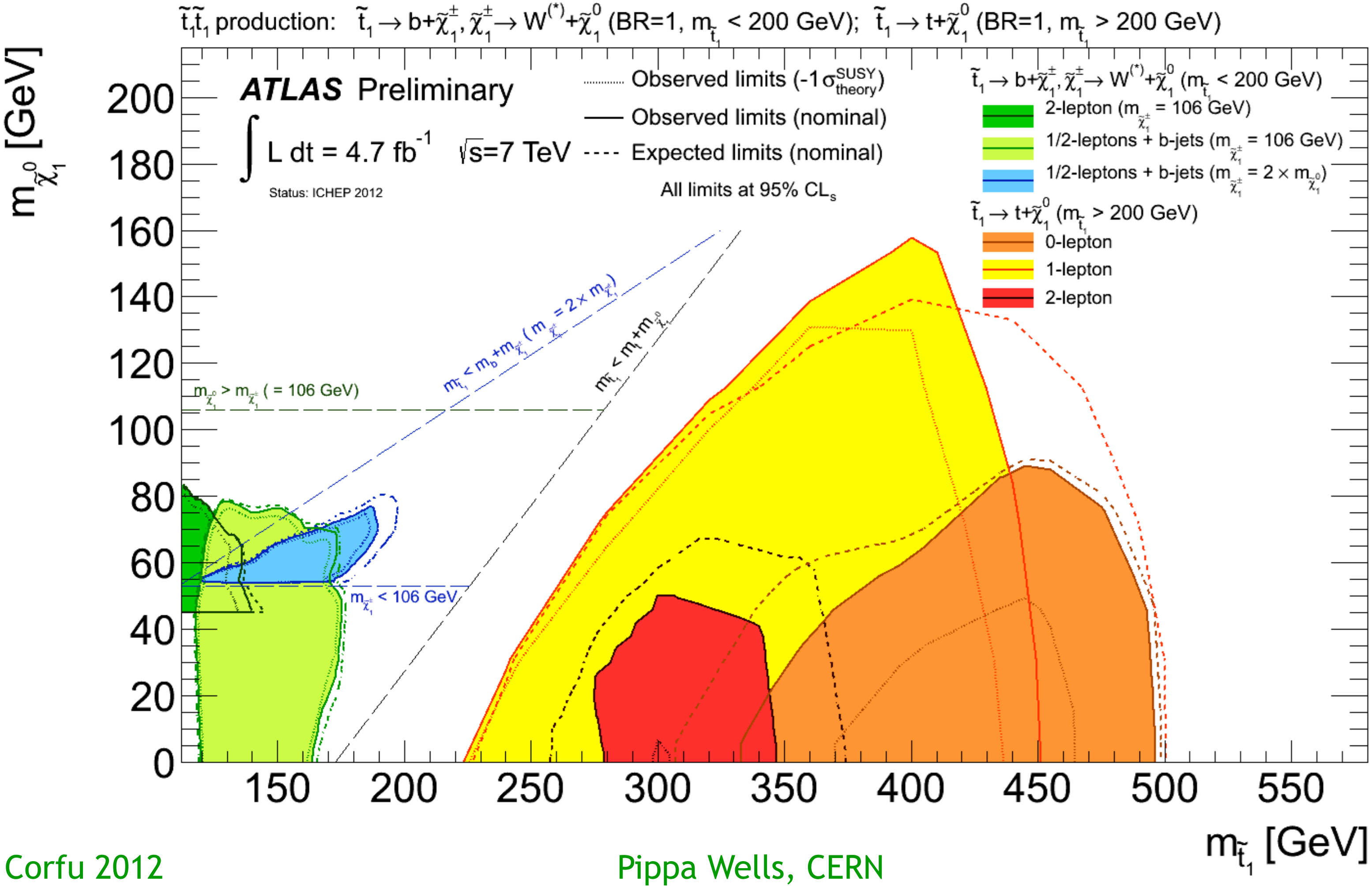


- Expect b-jets in the final state (maybe via top decay)
- Interpretation depends on mass hierarchy and stop/sbottom decay mode

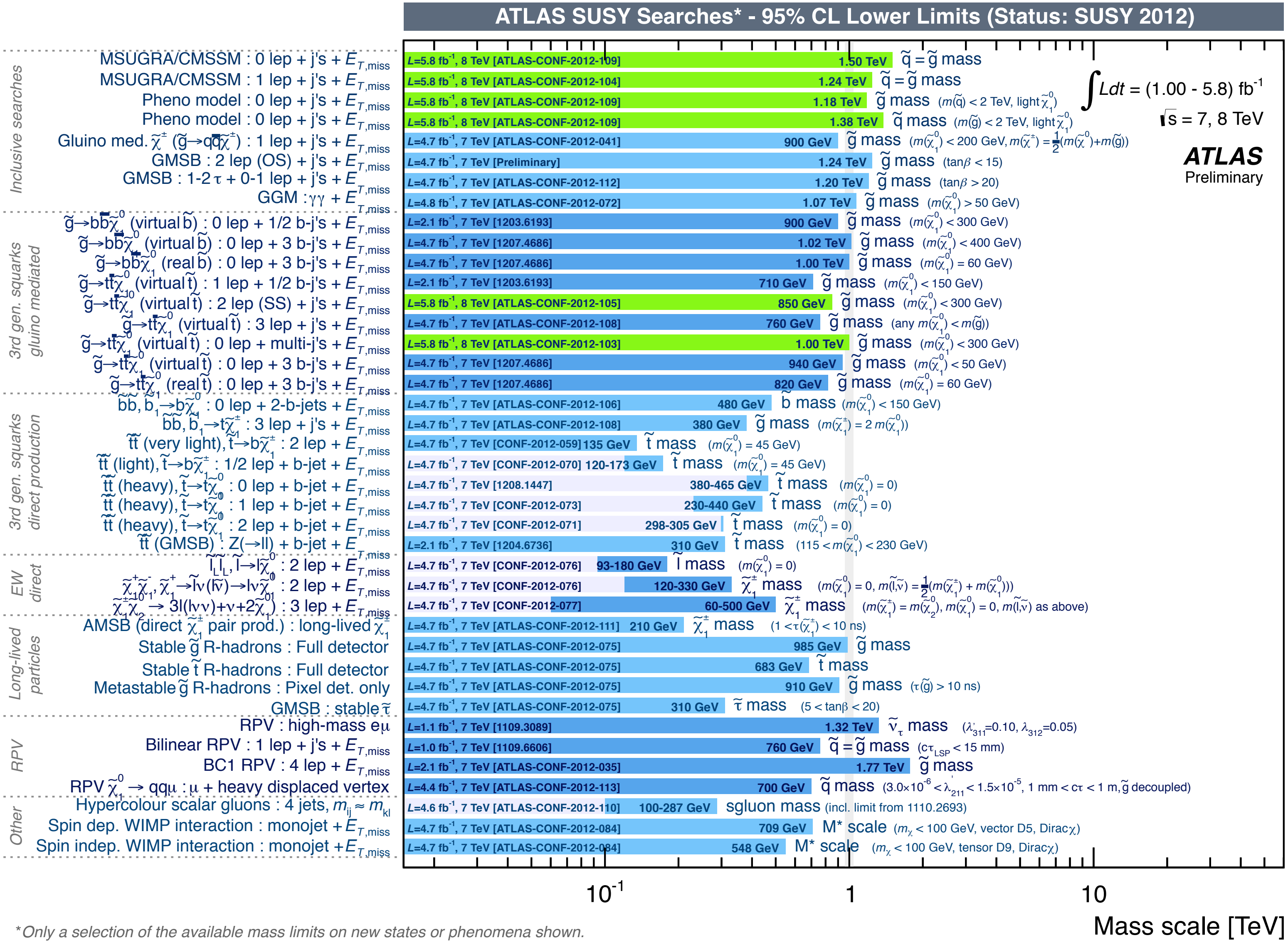
Stop pair production

[1] ATLAS-CONF-2012-059
[2] ATLAS-CONF-2012-070
[3] ATLAS-CONF-2012-071
[4] ATLAS-CONF-2012-073
[5] ATLAS-CONF-2012-074

- left: $m(\tilde{t}) < 200\text{GeV} : \tilde{t} \rightarrow b\chi^{\pm}, \chi^{\pm} \rightarrow W\chi^{0}$
  $m(\chi^{\pm}) = 106\text{GeV}$ or $m(\chi^{\pm}) = 2m(\chi^{0})\text{GeV}$
- right: $m(\tilde{t}) > 200\text{GeV} : \tilde{t} \rightarrow t\chi^{0}$



SUSY summary (beware the fine print!)



*Only a selection of the available mass limits on new states or phenomena shown.
All limits quoted are observed minus 1σ theoretical signal cross section uncertainty.

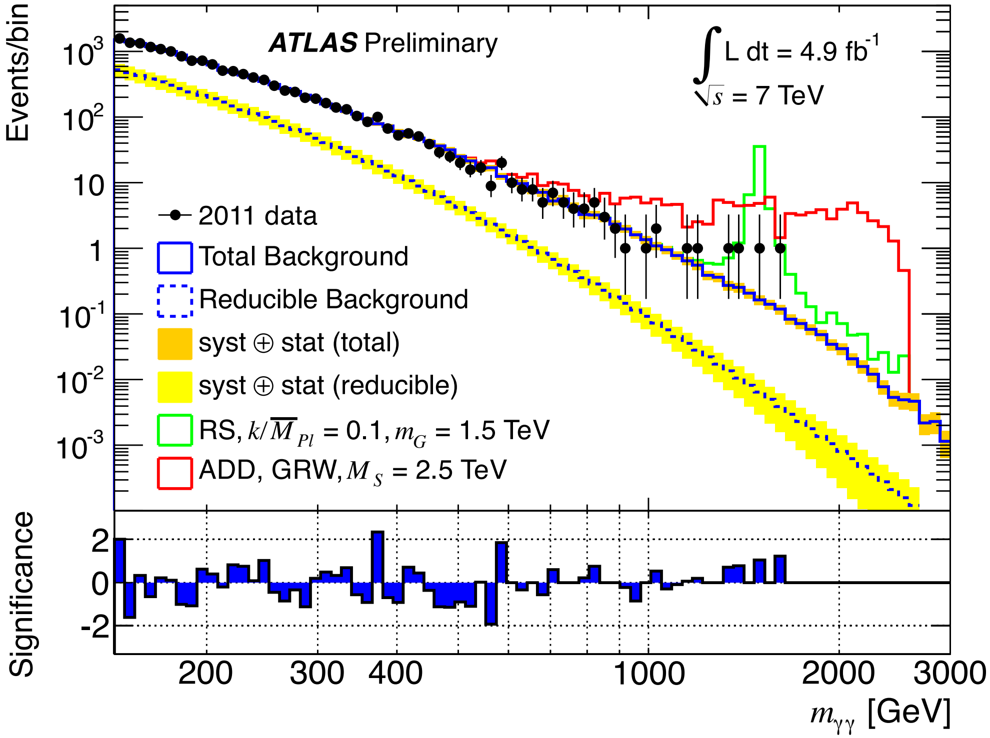
Exotica

- Generic term used for non-SUSY, non-Higgs searches
- Searches characterised by:
  - "bump hunting" (new resonances) with jets, leptons, photons, ttbar...
  - anomalous angular distributions (deviations from SM)
  - spectacular signatures
- Topologies of Higgs and SUSY searches can also be relevant for other models

- A few examples follow
  - Comprehensive results here:
  - https://twiki.cern.ch/twiki/bin/view/AtlasPublic/ExoticsPublicResults

Di-photon invariant mass spectrum

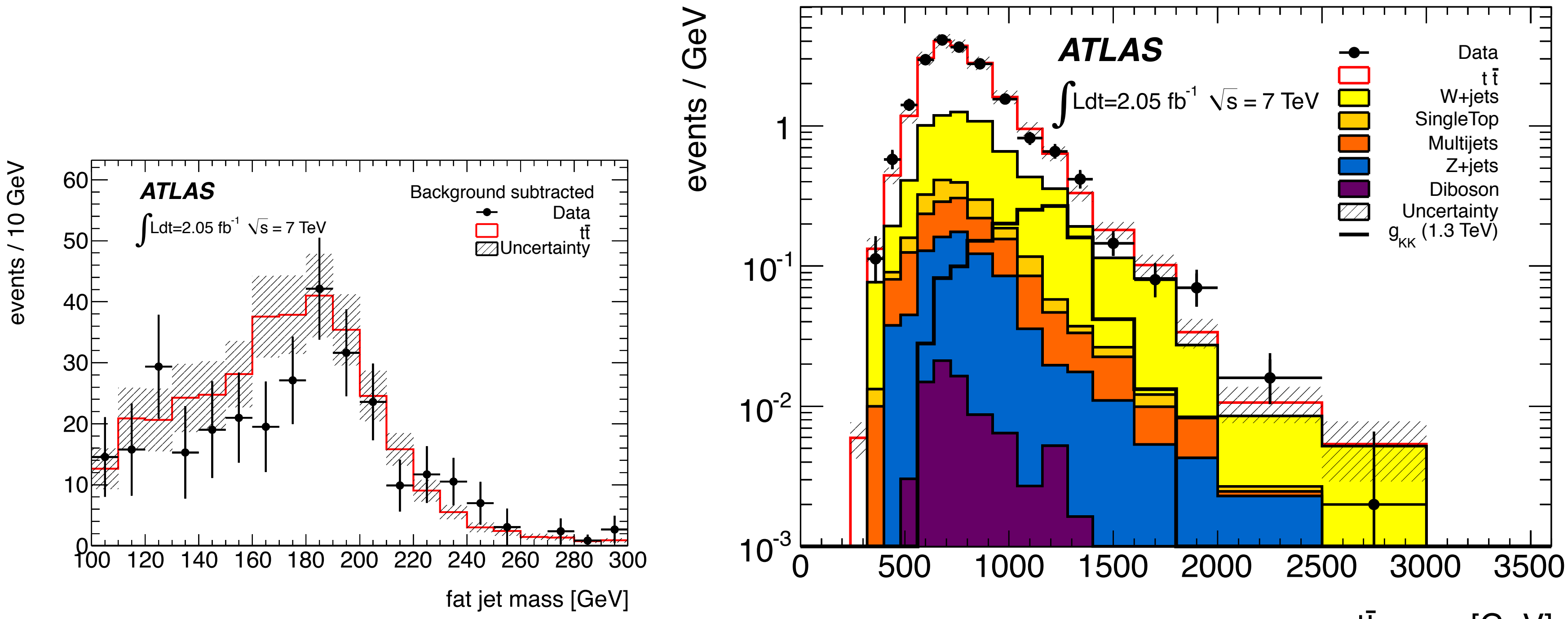
- Search for extra dimensions:
- Arkani-Hamed, Dimopoulos and Dvali model – closely spaced resonances look like continuum with effective cut-off scale M_S
  - Limits on M_S in the range of 2.62-3.92 TeV
- Randall-Sundrum gravitons: resonances ~TeV apart.
  - Limits on mass of lightest graviton of 1.00 (2.06) TeV, for coupling parameter k/M_{Pl} 0.01 (0.1)



arXiv:1207.2409 [hep-ex]

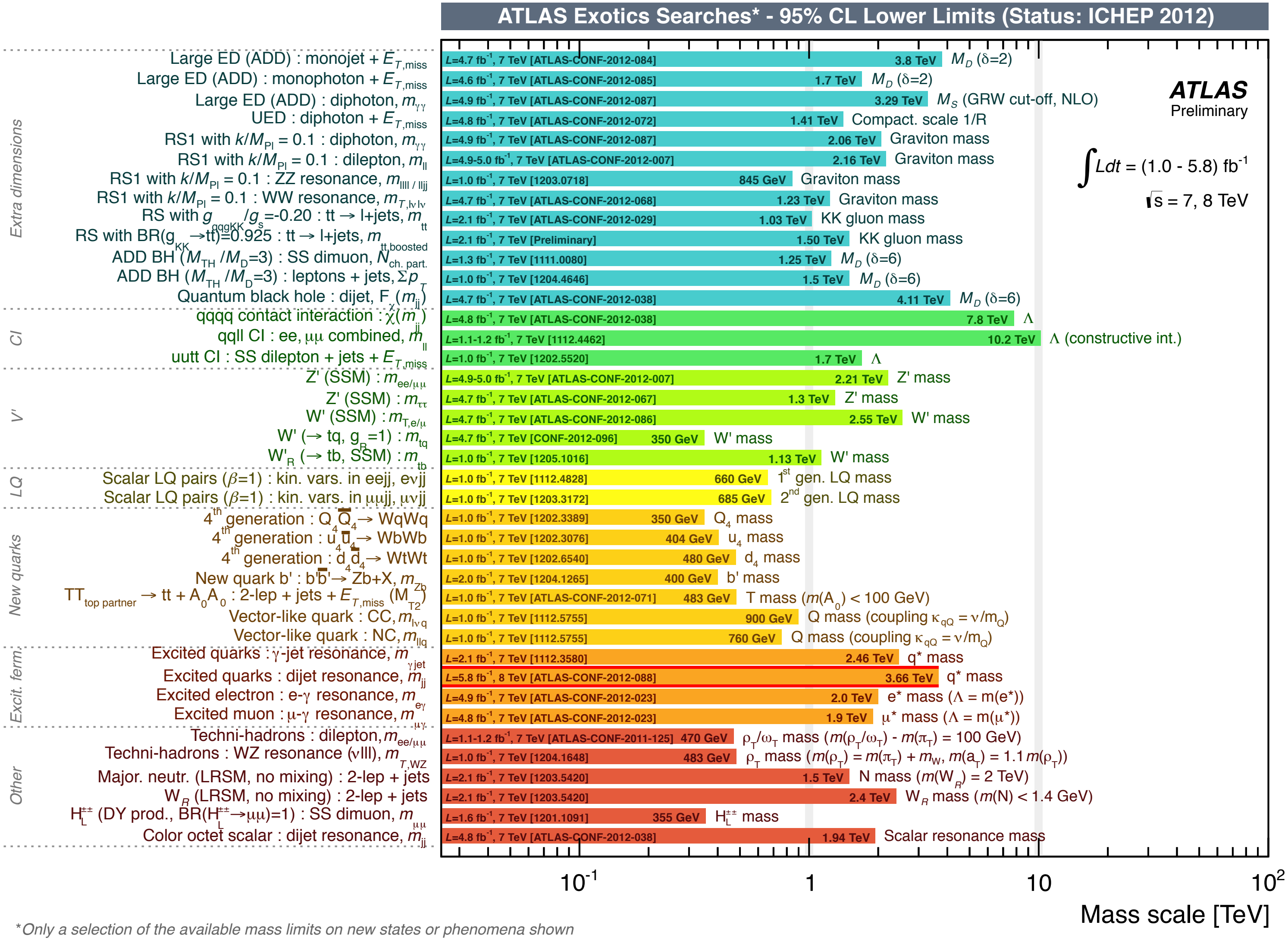
Searches with top quarks

- Example: high mass ttbar resonances
  - lepton+jets final state
  - boosted top quarks reconstructed as fat jets
  - Kaluza-Klein gluons excluded with mass below 1.5 TeV



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

No new discoveries yet



1 10 TeV

Conclusions and outlook

- LHC machine and ATLAS experiment have performed fantastically well at 7 and 8 TeV centre-of-mass
- The Standard Model stands firm – good agreement with almost all measurements
  - Improvements in description with increased sophistication of calculations, new pdfs etc.
- A new boson has been observed, with mass 126 GeV and properties so far consistent with SM Higgs
- No discoveries so far from direct searches for SUSY or other beyond the SM physics
- Long future for the LHC

- We are enjoying the chance to live in interesting times!