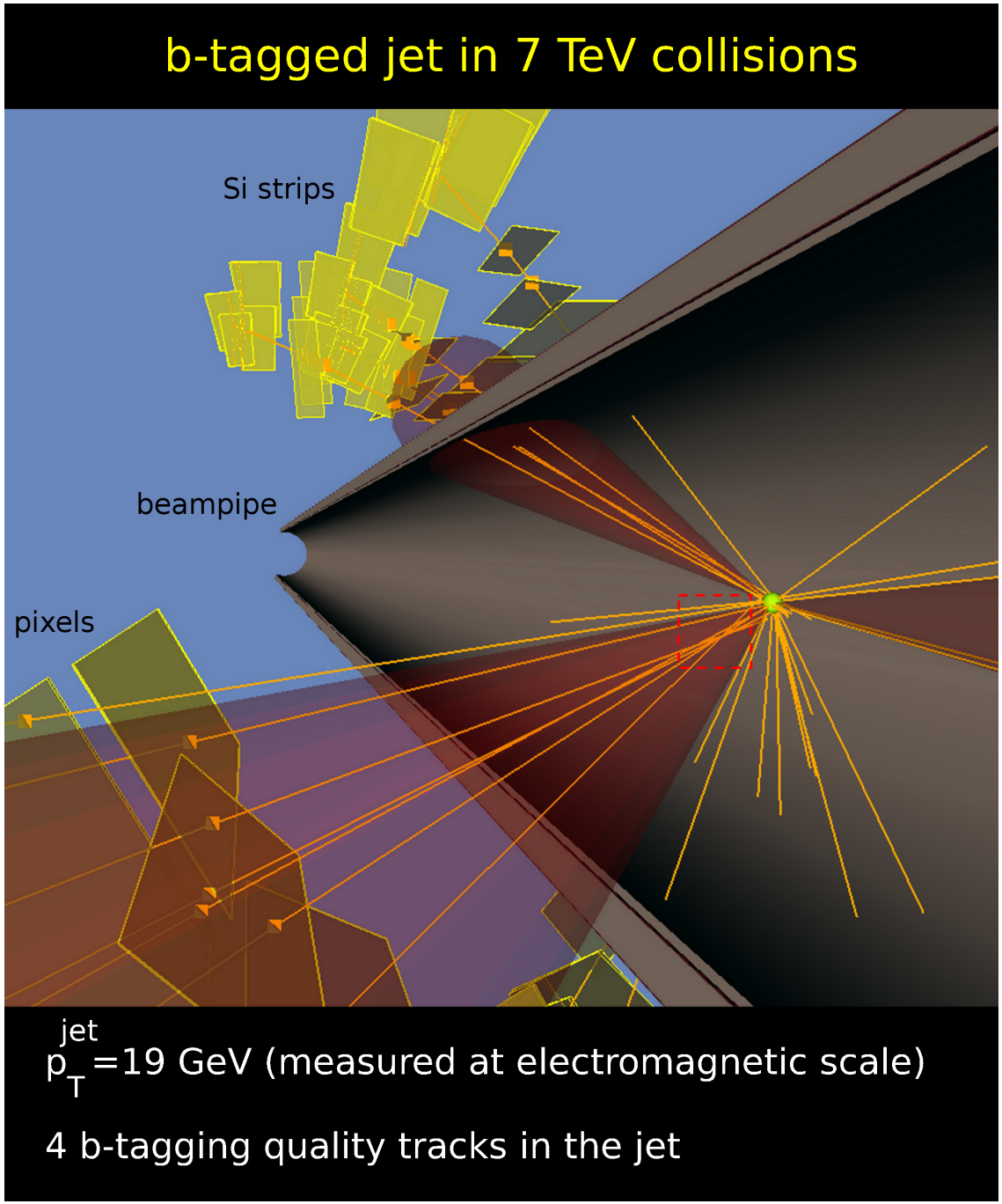


Search for the Higgs Boson in the bb Channel

with 4.7 fb^{-1} of Data Taken in 2011 with the ATLAS Detector

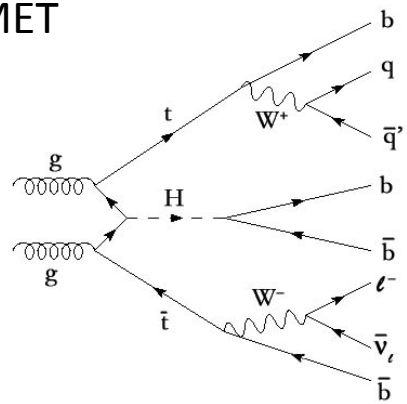
Marumi Kado

Laboratoire de l'Accélérateur Linéaire (LAL)
IN2P3, CNRS

Terascale workshop on Interpreting Emerging Higgs Data 04/04/12

Why the ttH→bb Channel Disappeared from Radar Screens?

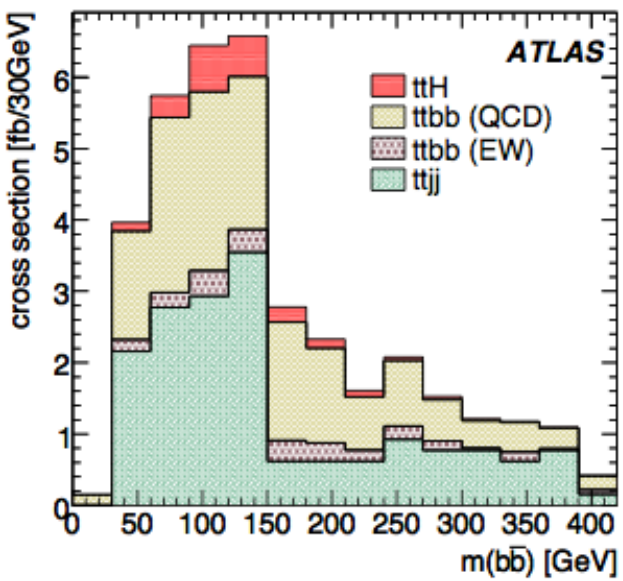
- Very important to check the Yukawa nature of the Higgs-fermion coupling
- Originally very promising channel ~O(H→γγ) in the low luminosity scenario…
- However a very intricate final state… 6 jets (4b), one lepton and MET
  - Very large combinatorial background
  - Very large and uncertain ttbb and ttjj (no obvious control samples)



Very dilute channel at 120 GeV/c^2 : s/b ~ 10%

but no definite mass peak

Sensitivity for 30 fb^{-1} (14TeV): s/√b ~ 2



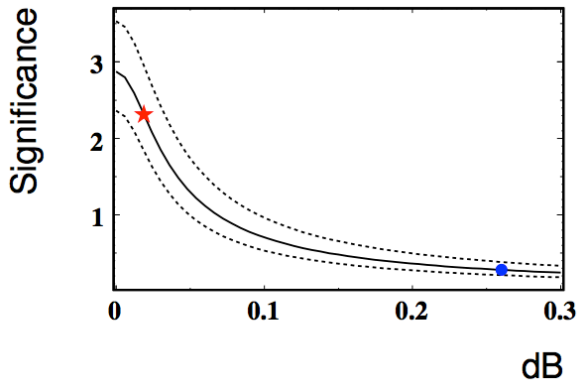
Without systematic uncertainties…

None with systematics

What could be done ?

Perhaps experimentally use multivariate techniques or improved b-tagging, but…

Mostly needs guidance from theory :



-Simulation to higher orders of ttbb and ttjj ?

-Overlaps treatment ?

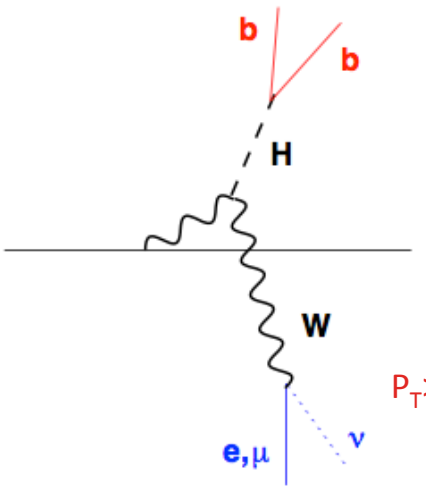
… or new ideas …

The Associated Production W/ZH→bb Channels Never Really Made it to the Radar Screen… Until Recently

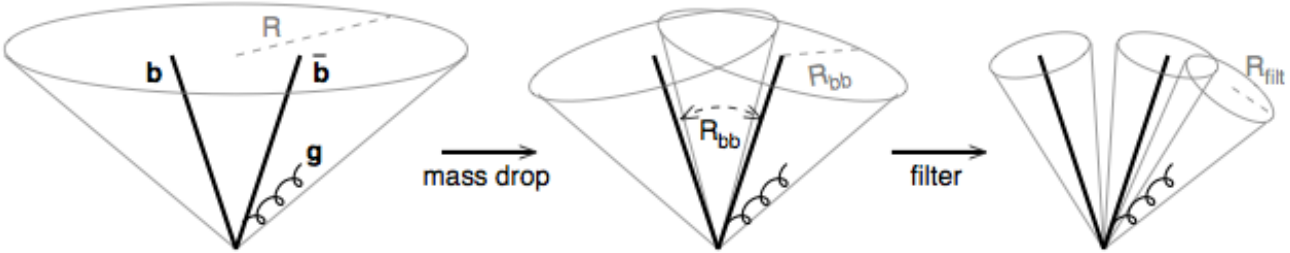
Idea : - Use Higgs only at high p_T to improve acceptance and reduce bkg.

- The Higgs would be a single jet, then investigate the jet structure

Butterworth, Davison, Salam, Rubin



P_T> 200 GeV/c



Fat jet
With mass m

- Use the Cambridge-Aachen jet algorithm Dokshitzer et al. 97'
  (Clustering based on the R-distances between objects, iterate until ΔR>1.2)

- Undo the last stage of clustering defining J_1 and J_2

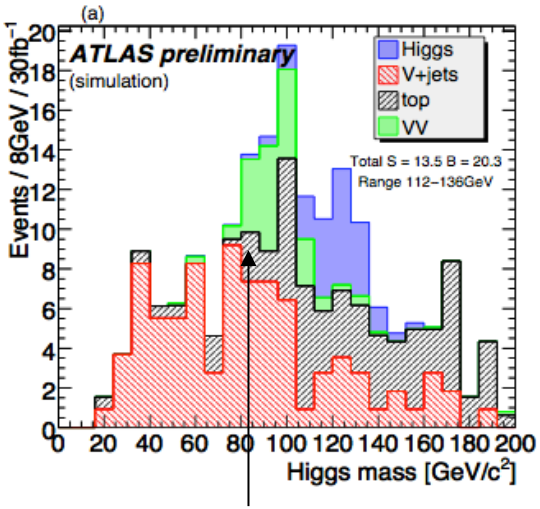
  If $\max(m_1,m_2) < 2m/3$ then there is a "mass drop"

- If there is a mass drop apply b-tagging

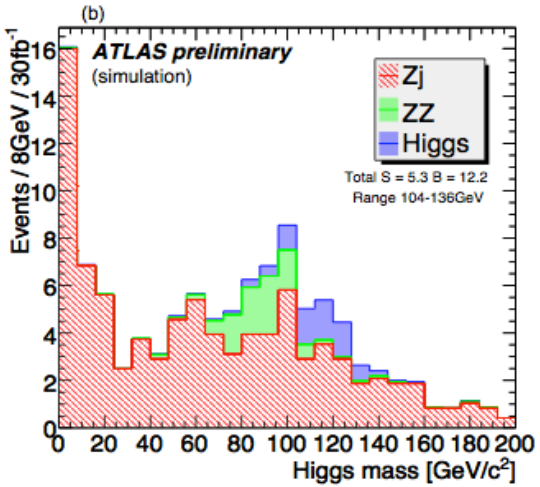
- Then recluster using a $R_{filt} = \min(0.3, R_{J1,J2})$

ATLAS has performed this search with full Monte Carlo simulation in three channels…

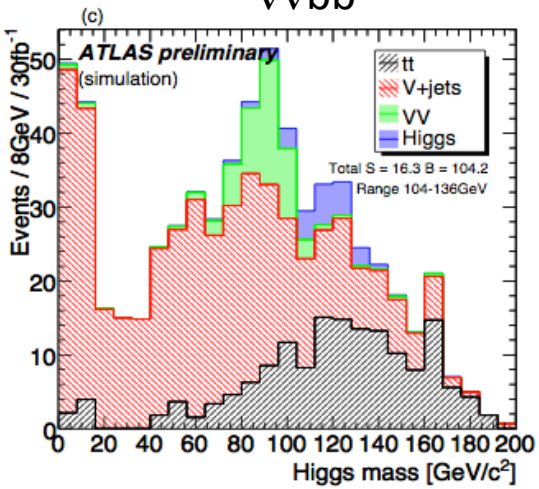
lνbb



llbb



ννbb



Z mass peak clearly visible!

A combined significance of ~3.0 - 3.7σ is expected for 30 fb^{-1}
(depending on the systematic uncertainties on main backgrounds)

- Very promising/discovery channel
- bb branching is critical to assess Higgs properties (See talk by T. Plehn)

Revival of the ttH channel also foreseen using a similar technique…

T. Plehn, G. Salam, M. Spannovsky, KA-TP-12-2009

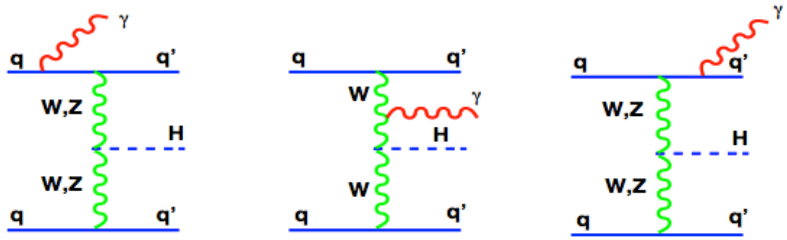
- A similar technique applied requiring at least two fat jets and a lepton (2 or 3 b-tags)
- Combinatorial background not a problem
- Sensitive only at around 100 fb^{-1} (4-5σ sensitivity)

Analyses still need to be performed by experiments with full simulation

Another idea waiting for a word from experiments…

The VBF with an additional photon

E. Gabrielli, F. Maltoni, B. Mele, M. Moretti, F. Piccinini and R. Pittau, Nucl. Phys. B **781**, 64 (2007)



Idea : -The extra photon will improve trigger efficiency

- Large gluonic bbjj(γ) background is suppressed

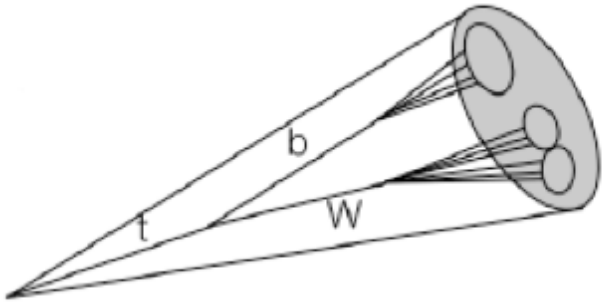
- Destructive interference reduces the irreducible background when requiring a high p_T photon

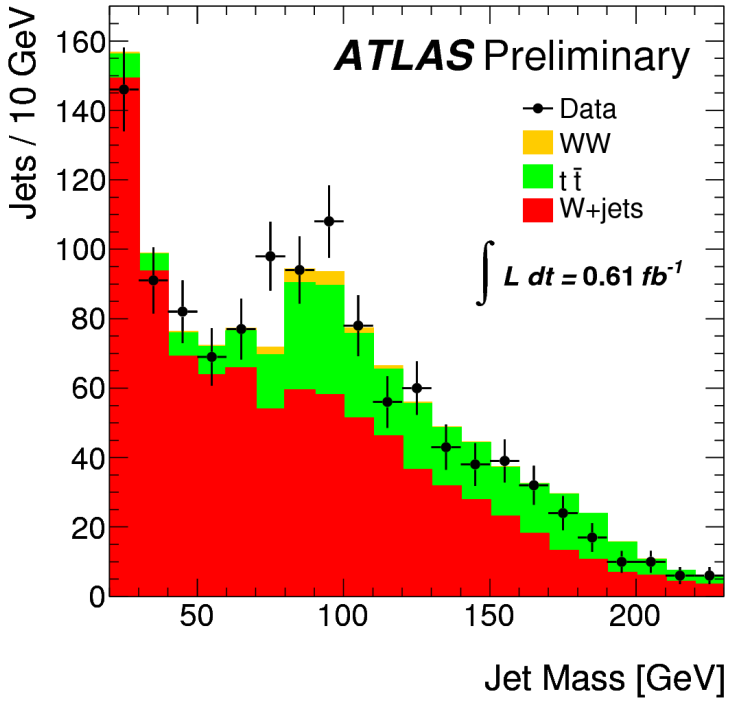
Signal reduction by ~α while
background is far more more reduced by ~1/3000 overall

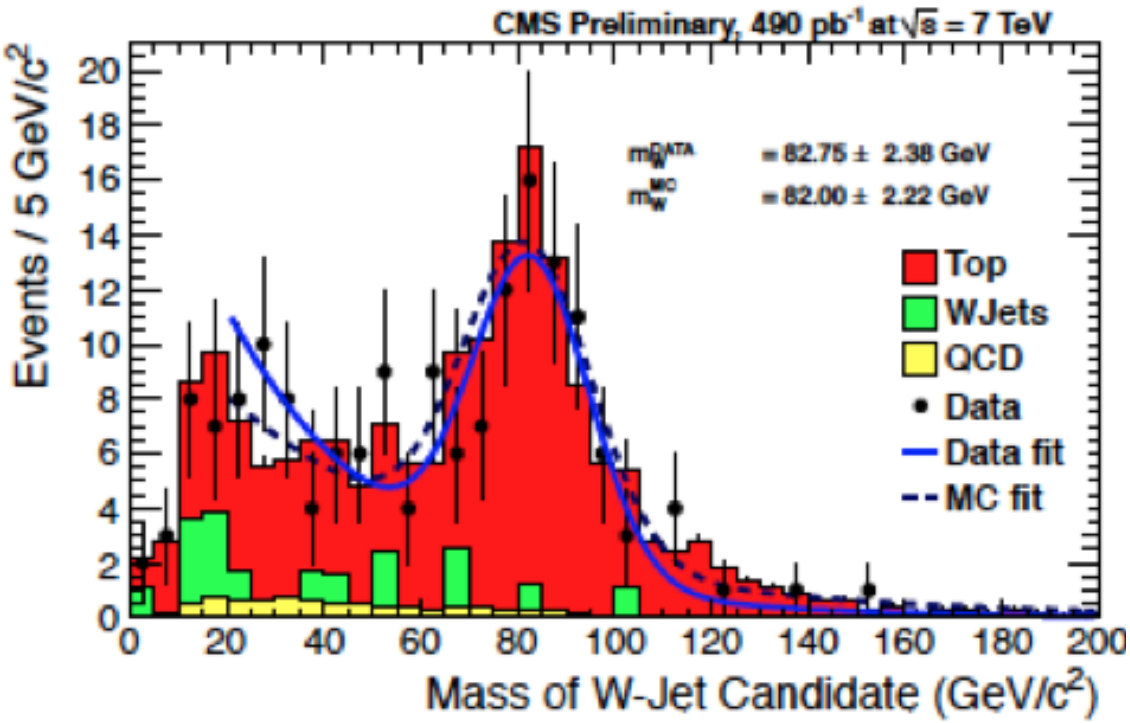
Interesting but will still need large amounts of luminosity :
About 3σ at 100 fb^{-1} and m_H = 120 GeV/c^2 studies are underway in experiments

Fat-Top-Jet Samples

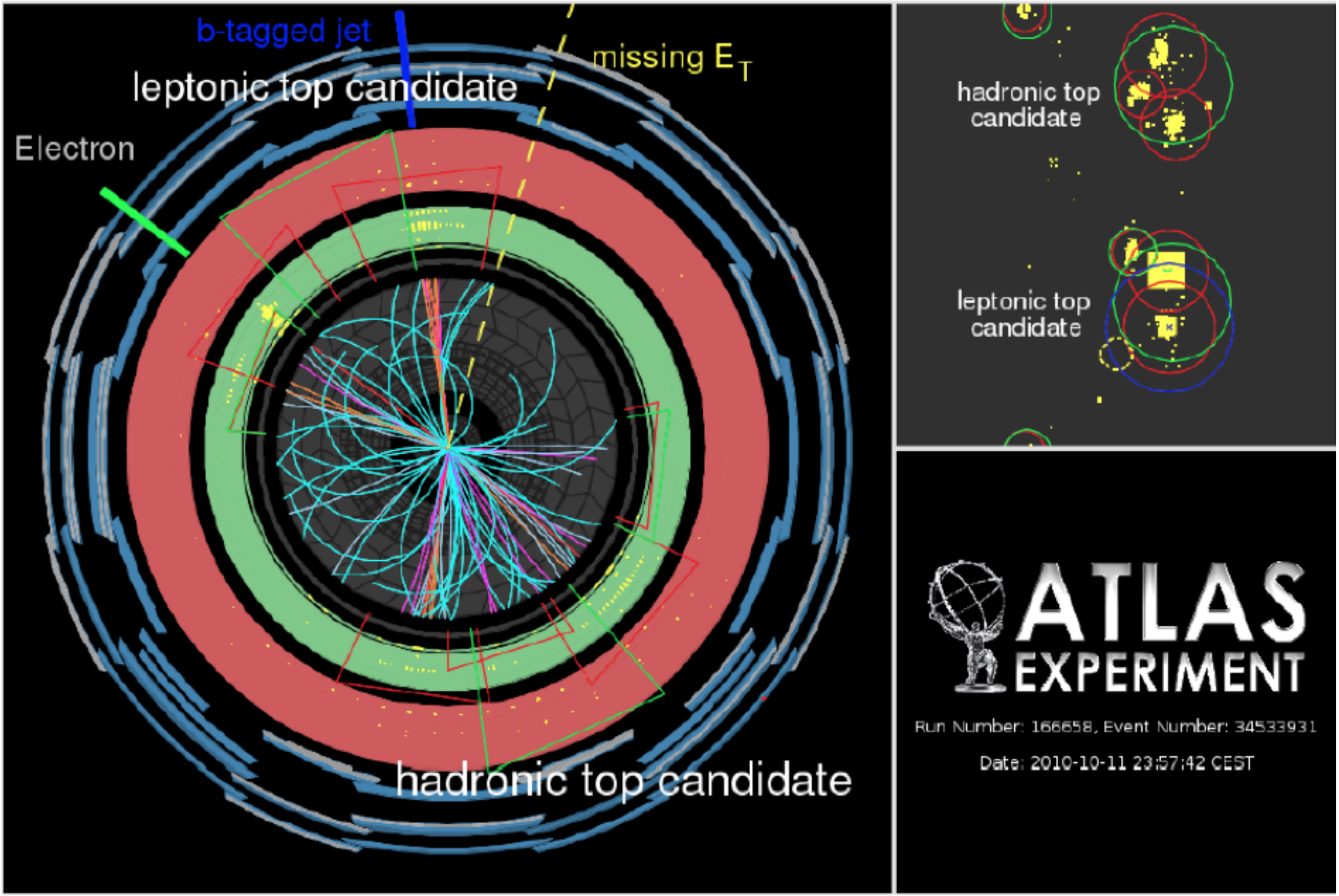
- Very encouraging first results (top-jet) :







Hadronic Top Candidate (E_T = 356 GeV, 3 subjets, M=197 GeV)



Preamble : Breakthroughs in Phenomenolgy

Several breakthroughs in the past decade have drastically changed the theory prospective to the hadron collider processes.

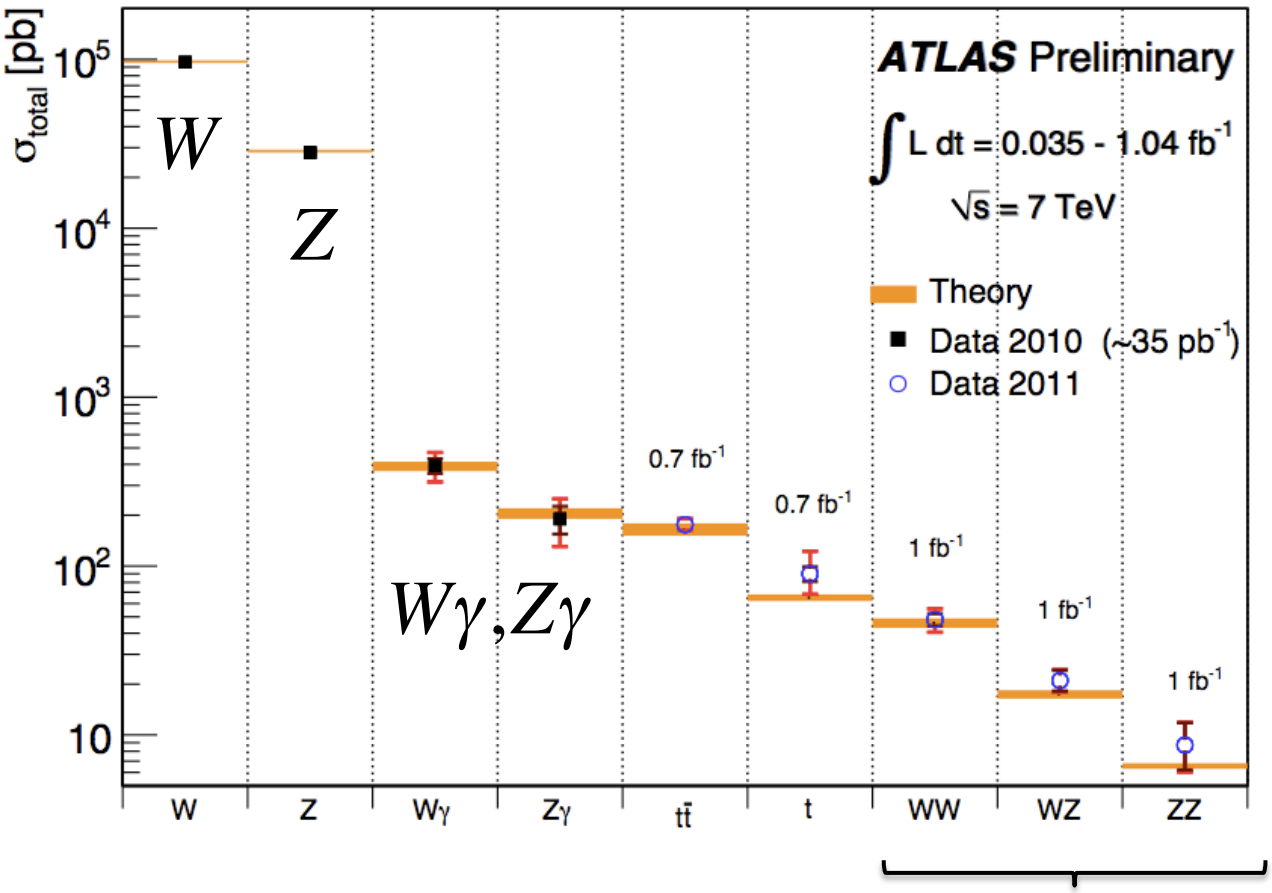
- The "Next-to…" revolution :
  - Breakthrough ideas in computation of loops (sewing together tree level amplitudes).
  - NLO generators, blackhat, NLOjet++, Phox, MCFM, etc…
  - NLO generators w/ PS, MC@NLO and POWHEG.
  - NLO+NLL or NNLL, CAESAR, ResBos, HqT
  - NNLO, FEHIP, FEWZ, HNNLO, DYNNLO
  - …
- NNLO PDFs sets
- Parton Shower (and Matrix Element matching) improvements :

  Pythia, Herwig, Sherpa and CKKW (1.3) and MadGraph (5.0) performing very well (Including description of the Pile Up and the underlying event).

- The Jet revolution (Fast Jet) : Allowing to compute in reasonable time infra-red safe k_T jets.

Preamble : Important Measurements

ATLAS Overview



Theory at NLO

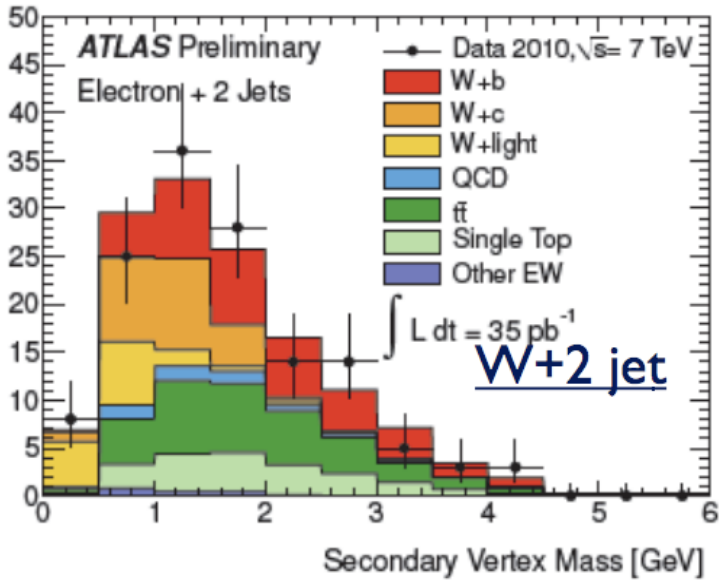
Measurement of di-boson production

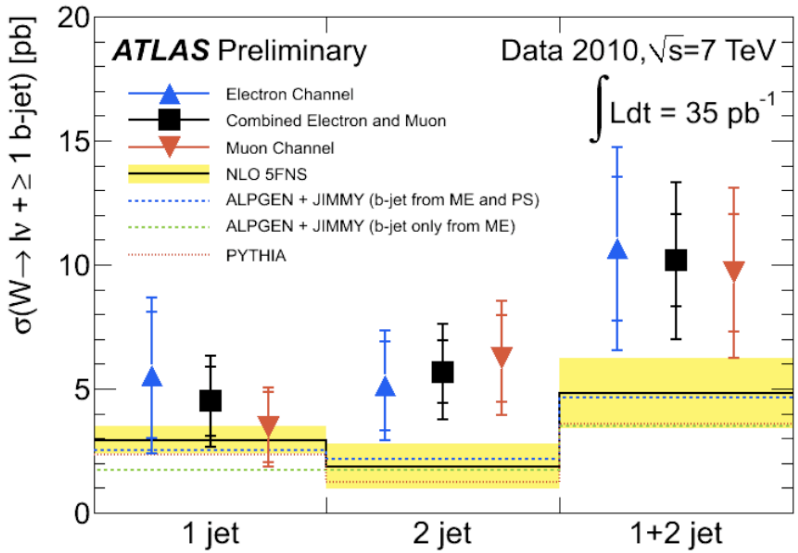
Preamble : Important Measurements

W-plus-HF

- W+Heavy flavor is dominated by Charm (Cabibbo favored sg production)
- Makes it a probe of strange content!
- Use the vertex mass to disentangle the W+b in ATLAS

These are very important control samples for the W,Z H to bb analyses!





Basic Selections

Preselections and objects :

1.- W : Only 1 lepton with p_T>25 GeV (with $|\eta|<2.5$)

2.- Z : 2 leptons with p_T>20 GeV (with $|\eta|<2.5$)

3.- Jets are 0.4 anti-k_T jets (with $|\eta|<2.5$)

4.- MET : Estimated from

- Clusters in the calorimeters (with $|\eta|<4.9$)
- Corrected if the clusters are associated to reconstructed objects (jets, electrons, photons and taus).
- Muons are included and the clusters in the calorimeter related to them are removed.

5.- MPT (Missing transverse p_T) : Vector sum of the transverse momentum of the tracks associated to the primary vertex.

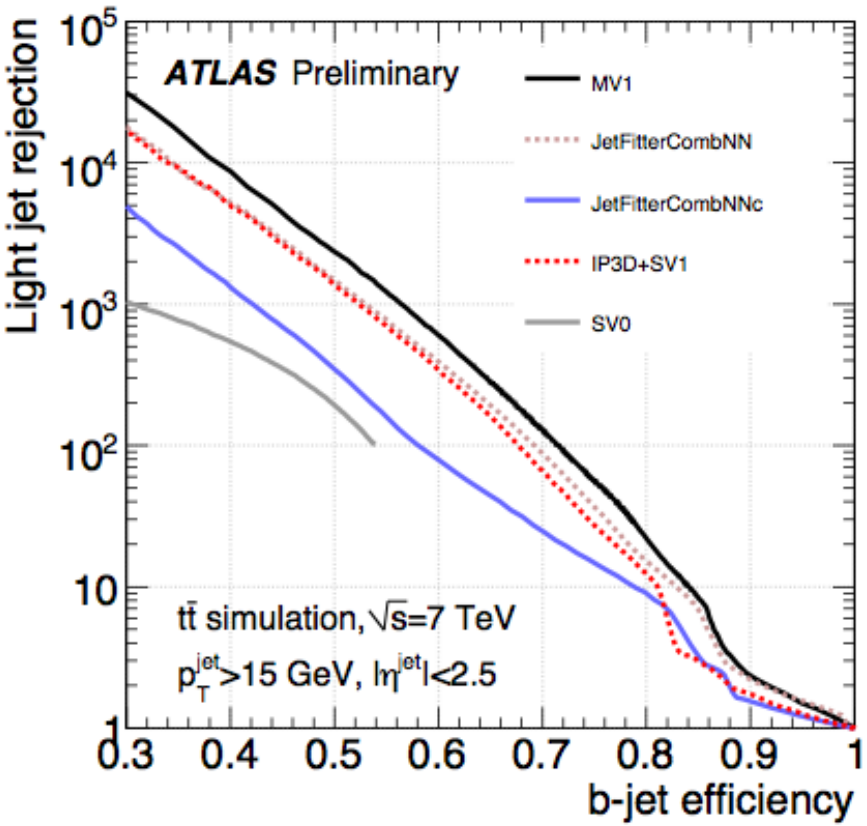
6.- b-tagging :

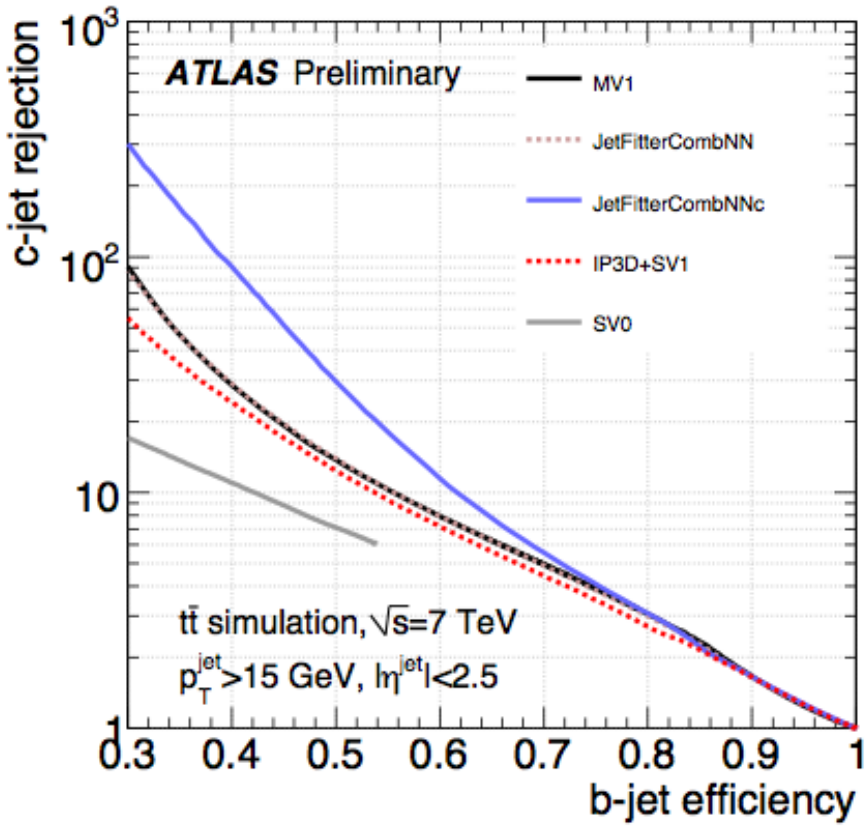
- Secondary vertex reconstruction
- IP probabilities combination

} Combined with an MVA (70% efficiency for b-jets in tt, 130 b-rejection and 5 c-rejection)

B-Tagging

Performance of the various taggers :

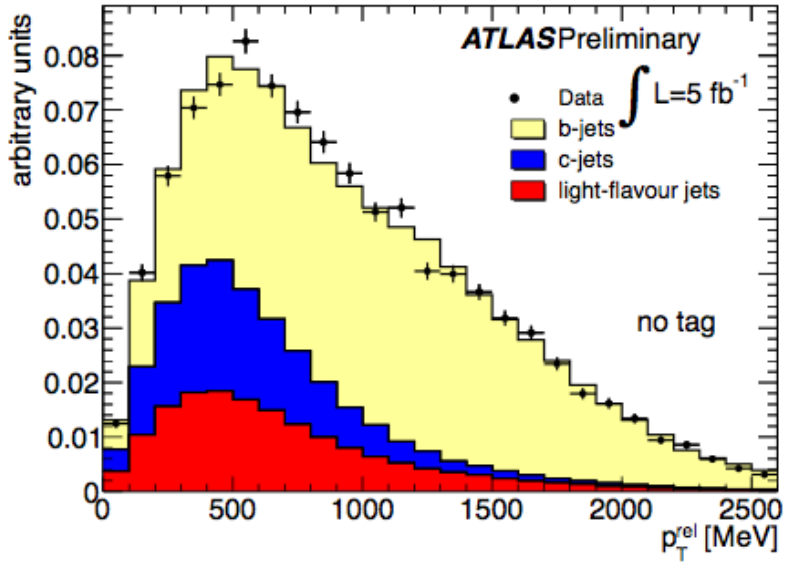


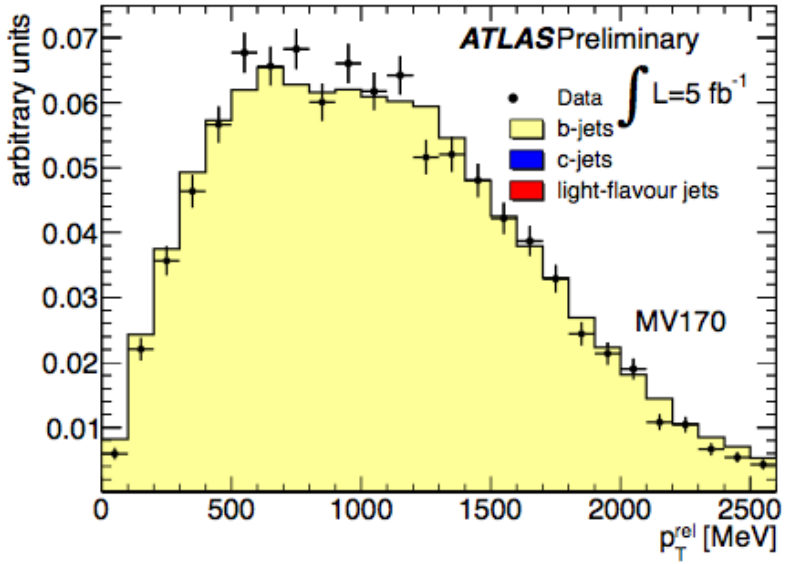


B-Tagging

Measurement of the B-tagging performance :

- p_T^{rel} method :





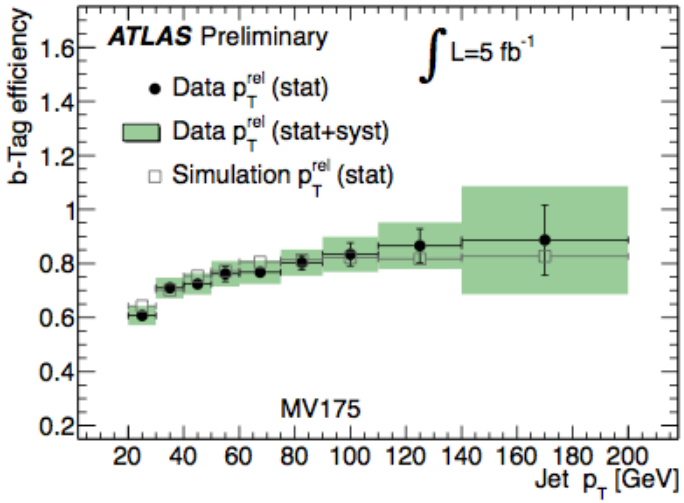
- System 8 : use three uncorrelated criteria

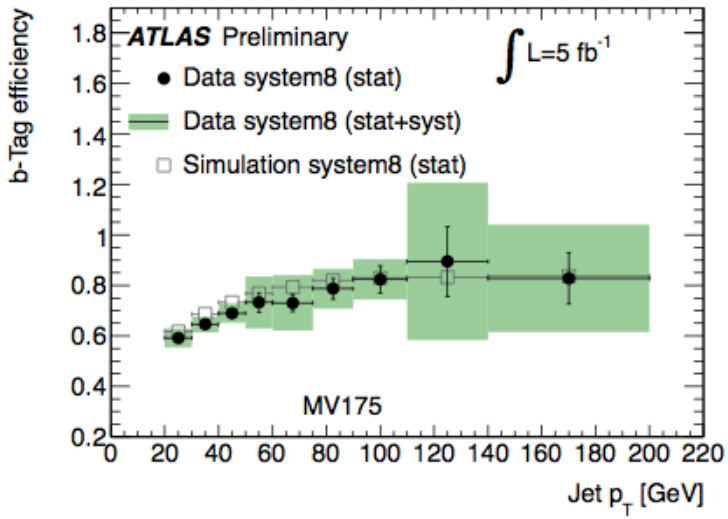
  - lifetime tagging
  - p_T^{rel} selection > 700 MeV
  - Presence of an opposite b-tagged jet

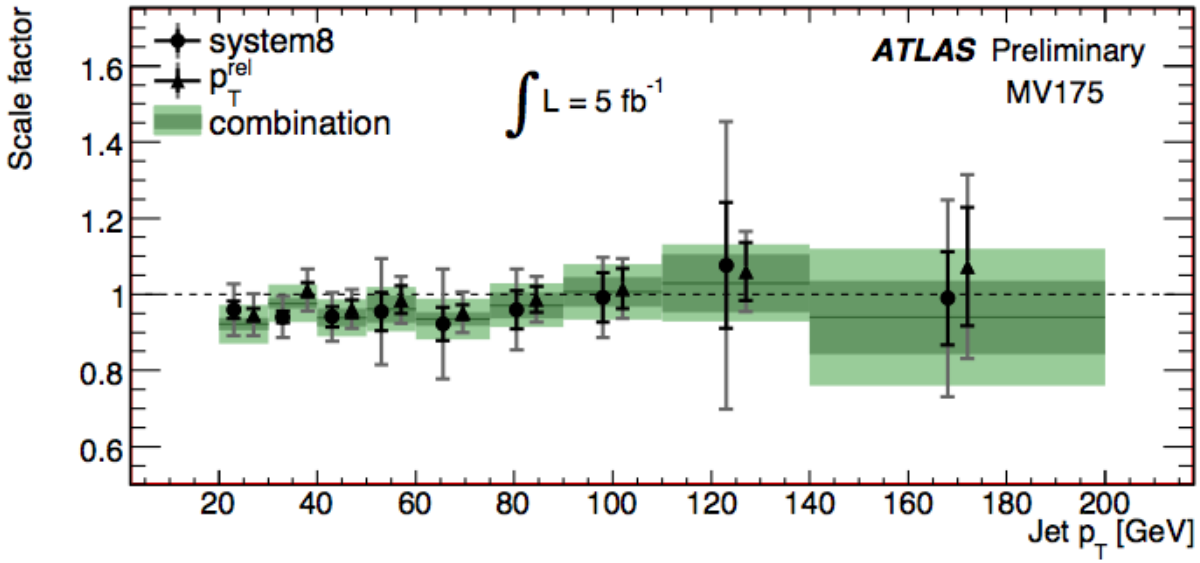
Eight equations with eight unknowns : the number of b and non-b jets passing the 3 selection criteria and originally present in the sample.

B-Tagging

Measurement of the B-tagging efficiency :







3 Main Channels

ZH (llbb) :

1.- Two oppositely charged leptons

2.- 83 GeV < m_{ll} < 99 GeV

3.- MET < 50 GeV to reduce top background

WH (lvbb) :

1.- Single lepton p_T > 25 GeV

2.- MET > 25 GeV

3.- m_T > 40 GeV

All events are required to have two b-jets with p_T>25, 45 GeV

WH (lvbb) :

1.- Large MET > 120 GeV

2.- PET > 30 GeV to suppress events which wrongly estimated MET

2.- $\Delta\Phi$(MET,MPT) < 90 deg.

Boost Categories

WH and ZH (lv, llbb) :

- $p_T^V < 50$ GeV ← In this case ΔR of the jets > 0.7
- $50 \leq p_T^V < 100$ GeV
- $100 \leq p_T^V < 200$ GeV
- $p_T^V \geq 200$ GeV

ZH (vv) :

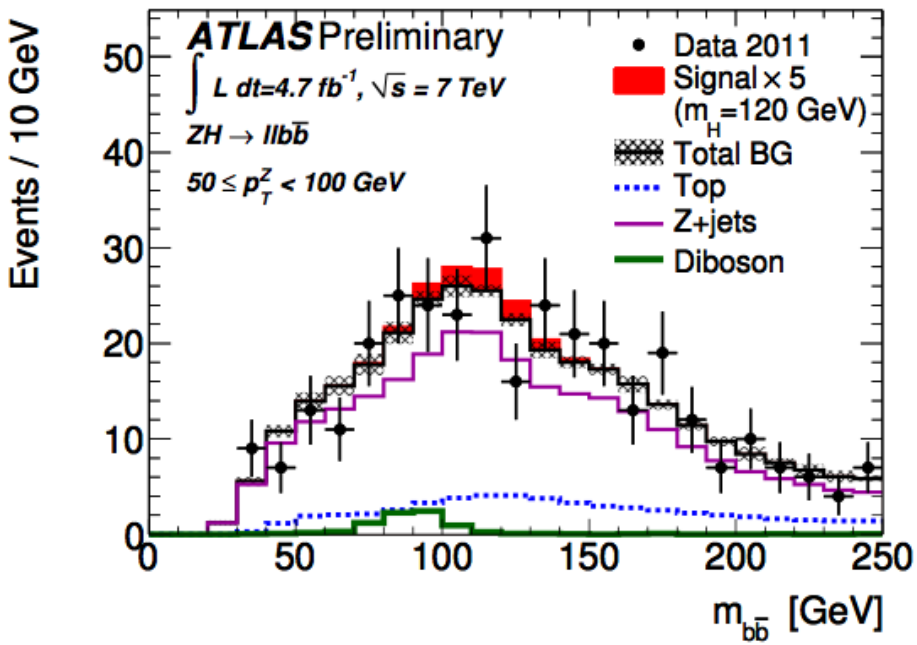
- $120 < E_T^{miss} < 160$ GeV
- $160 \leq E_T^{miss} < 200$ GeV
- $E_T^{miss} \geq 200$ GeV

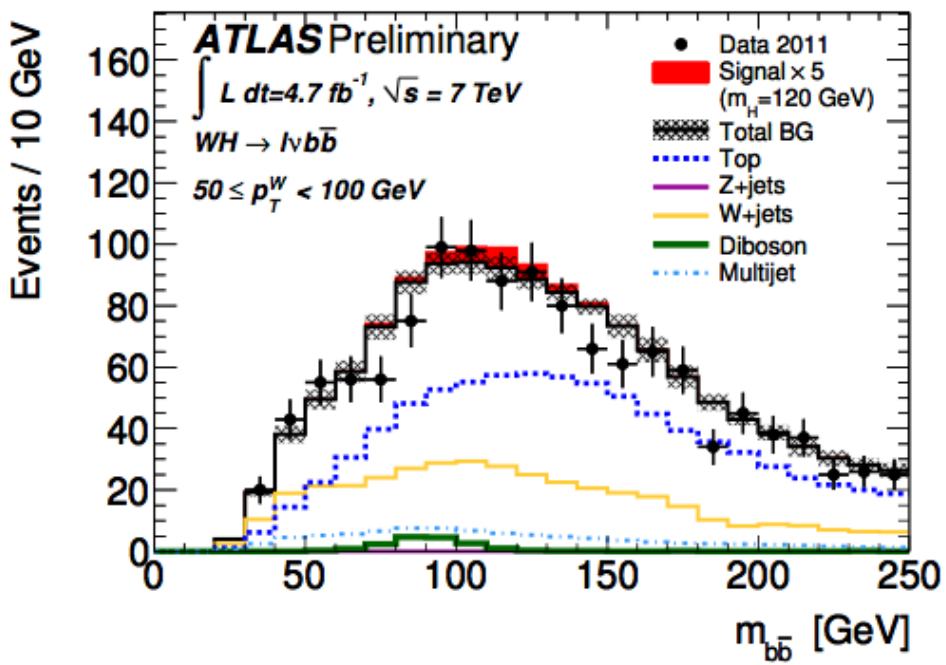
Background Estimates

- W/Z + jets : Shape from MC.
- Top : Shape from simulation as well.

lvbb : W+jets and top simultaneous fit of 3-jets (top) sample and m_{bb} sidebands

llbb : W+jets and top simultaneous fit of m_{ll} sidebands and m_{bb} sidebands





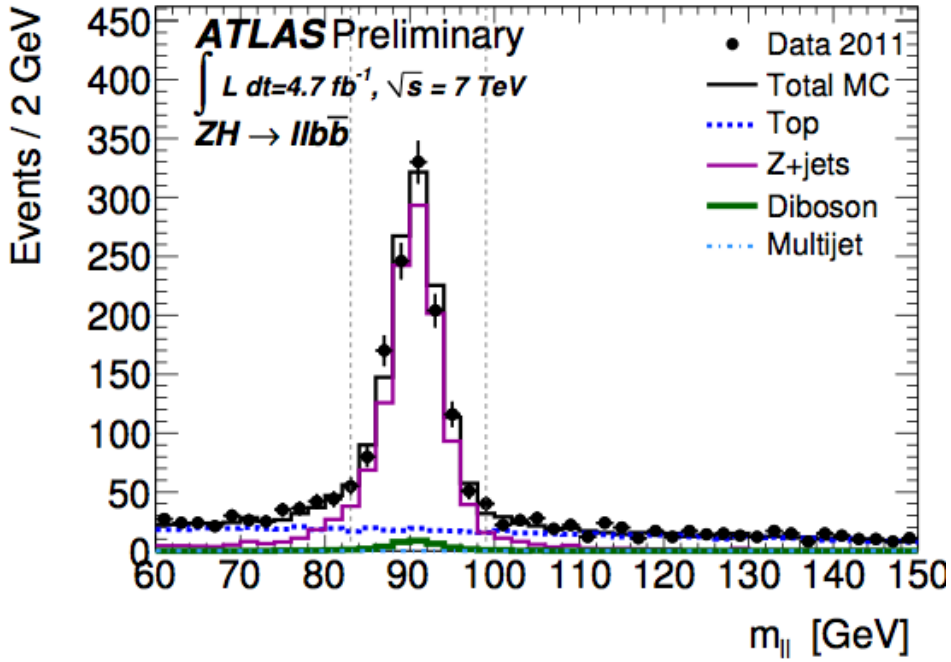
$$m_{b\bar{b}} < 80 \text{ GeV or } 150 \text{ GeV} < m_{b\bar{b}} < 250 \text{ GeV}$$

Background Estimates

- W/Z + jets : Shape from MC.
- Top : Shape from simulation as well.

lvbb : W+jets and top simultaneous fit of 3-jets (top) sample and m_{bb} sidebands

llbb : Z+jets and top simultaneous fit of m_{ll} sidebands and m_{bb} sidebands



$60\ \text{GeV} < m_{\ell^+\ell^-} < 76\ \text{GeV}$ or $106\ \text{GeV} < m_{\ell^+\ell^-} < 150\ \text{GeV}$

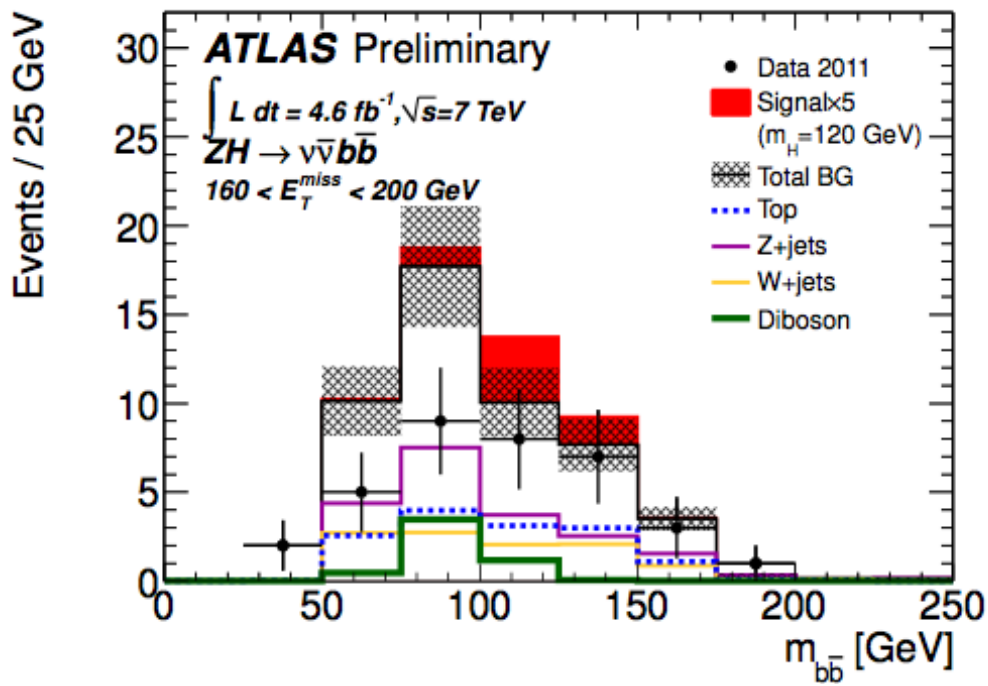
Background Estimates

- W/Z + jets : Shape from MC.
- Top : Shape from simulation as well.

lvbb : W+jets and top simultaneous fit of 3-jets (top) sample and m_{bb} sidebands

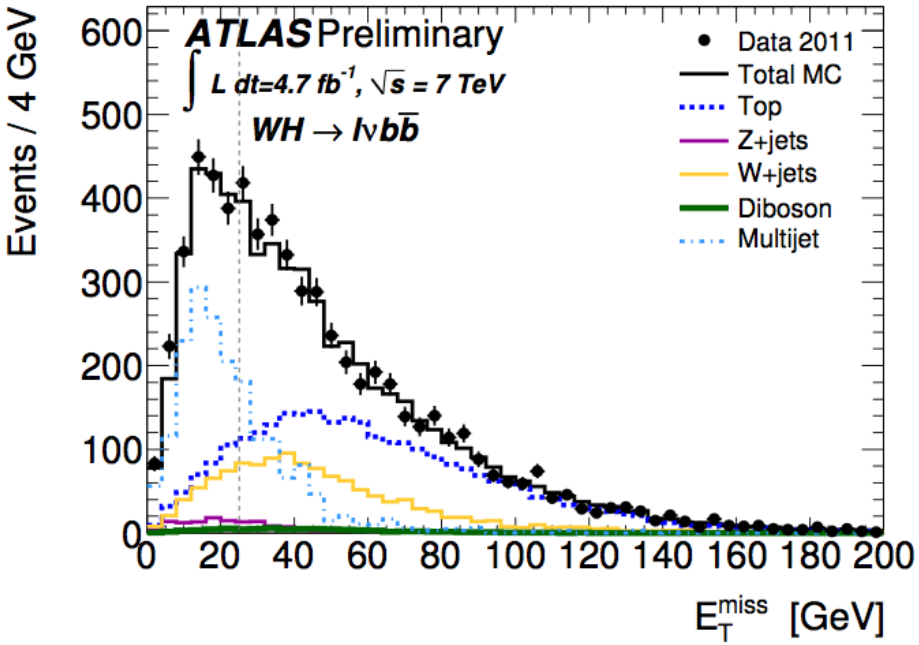
llbb : Z+jets and top simultaneous fit of m_{ll} sidebands and m_{bb} sidebands

vvbb : W+jets, Z+jets and top from the scale factors derived above



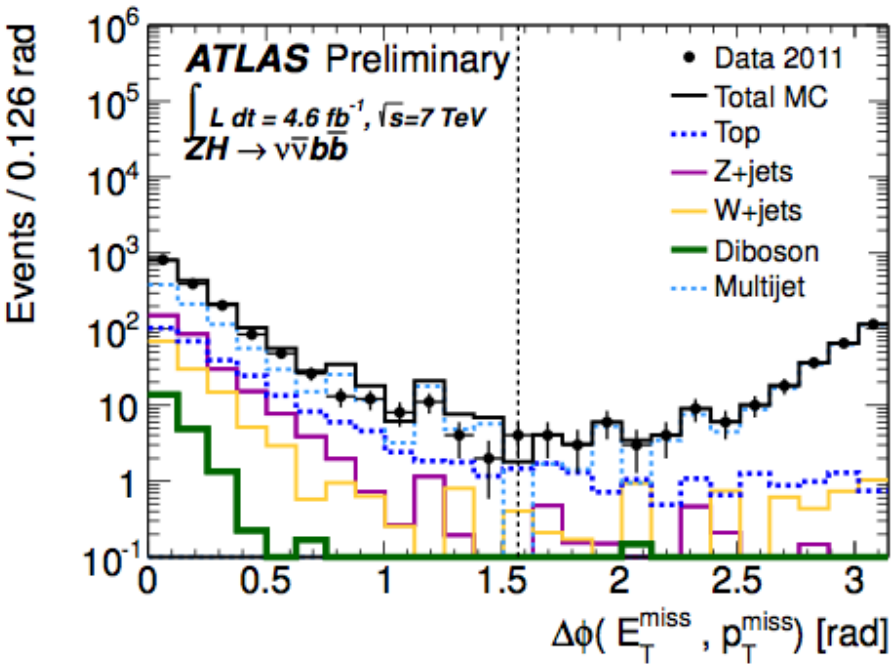
Background Estimates

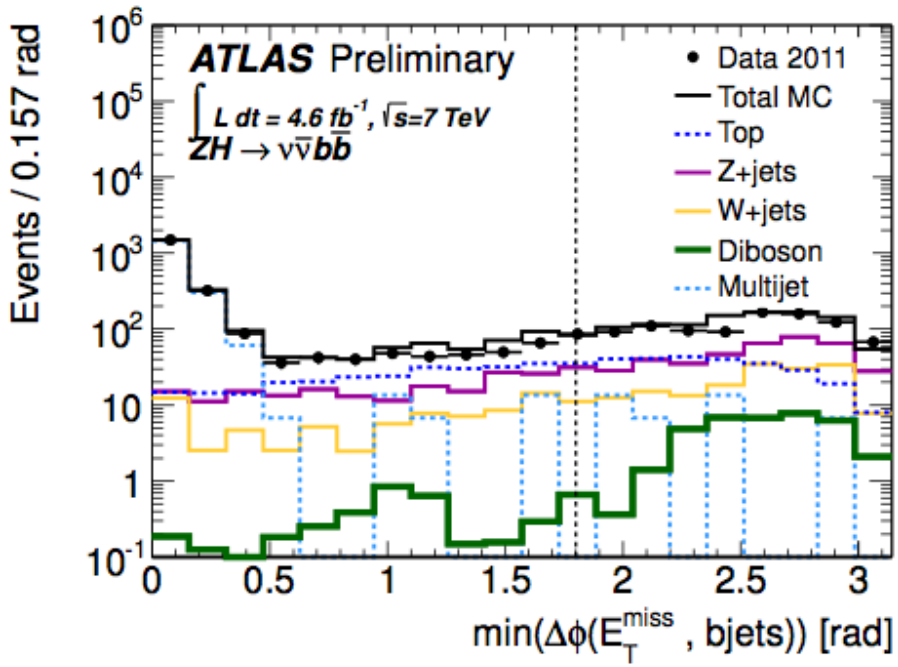
- W/Z + jets : Shape from MC and normalization of W/Z+2jets from <2 tags samples and m_{bb} sidebands
- Top : Shape from simulation and normalization from 3-jets sample, m_{ll} sidebands and m_{bb} sidebands
- Diboson : from MC (NLO cross sections)
- Multijet :
    - lvbb Fit of MET distribution, Temlate from reversed lepton ID (for the lvbb channel)



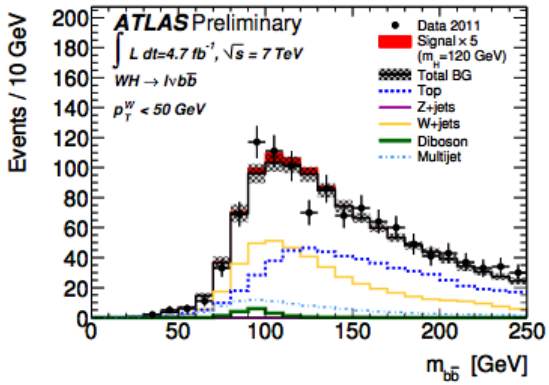
Background Estimates

- W/Z + jets : Shape from MC and normalization of W/Z+2jets from <2 tags samples and m_{bb} sidebands
- Top : Shape from simulation and normalization from 3-jets sample, m_{ll} sidebands and m_{bb} sidebands
- Diboson : from MC (NLO cross sections)
- Multijet :
  - lvbb Fit of MET distribution, Temlate from reversed lepton ID (for the lvbb channel)
  - vvbb channel use the min($\Delta\Phi$(MET,bjets))

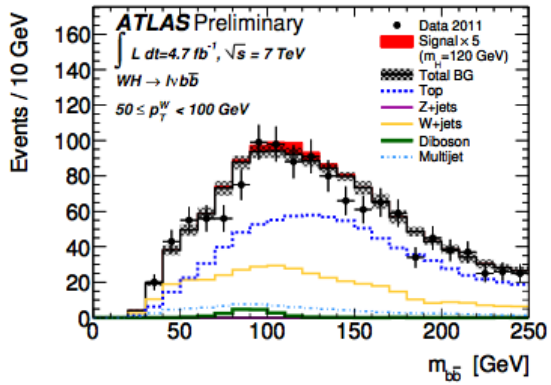




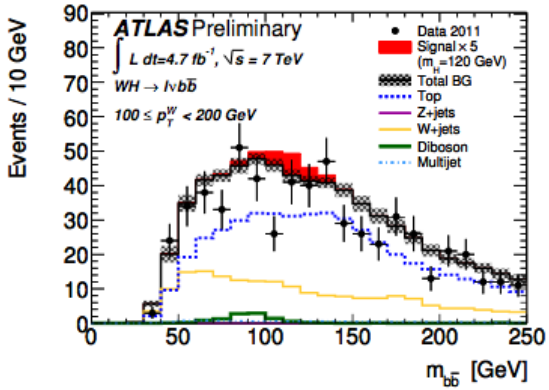
The lvbb Analysis



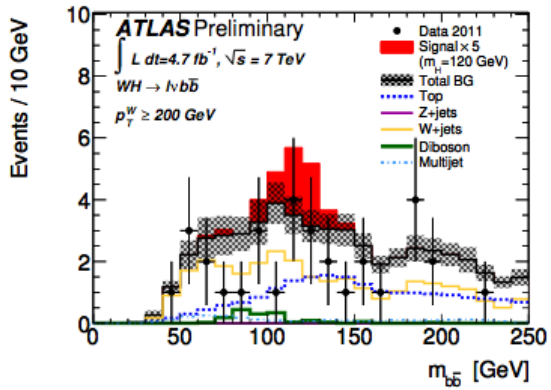
(a)



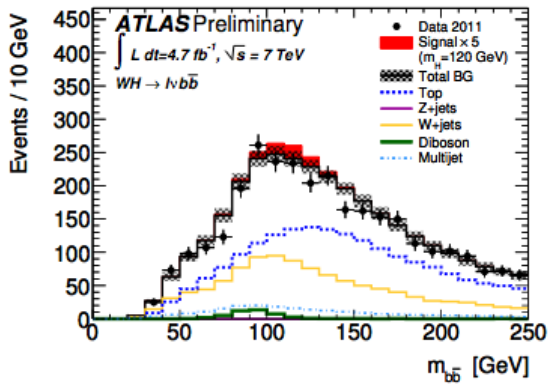
(b)



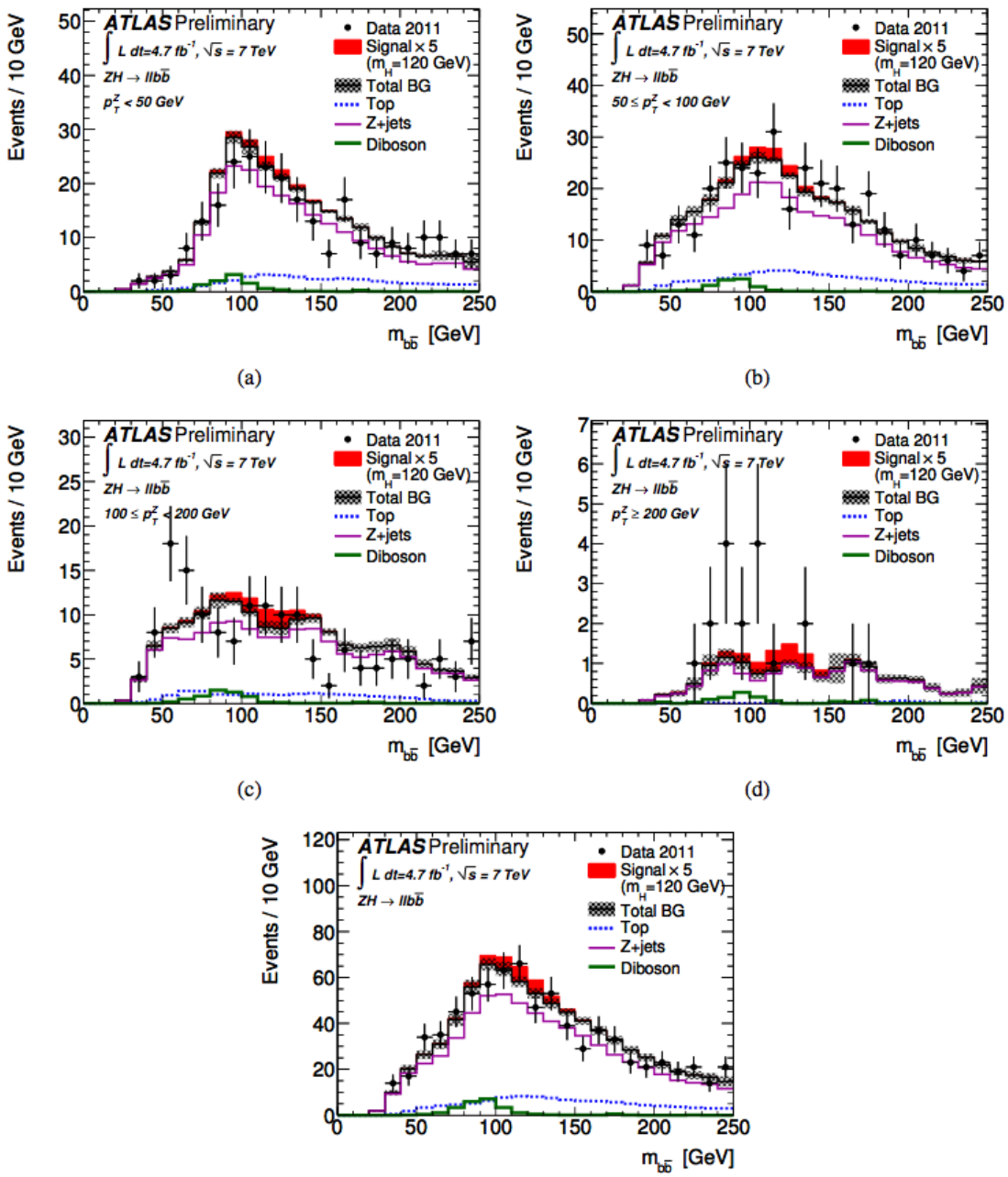
(c)



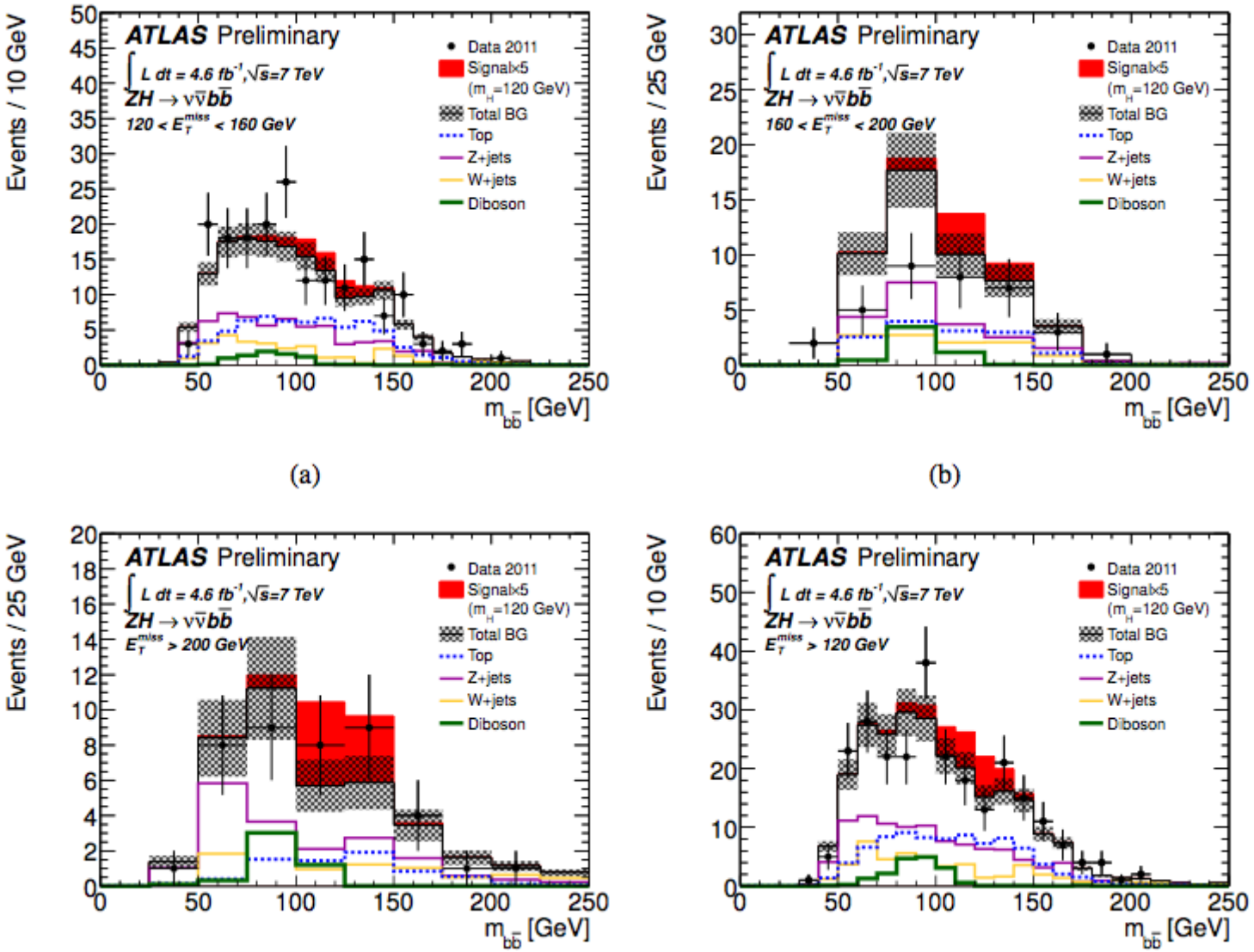
(d)



The llbb Analysis

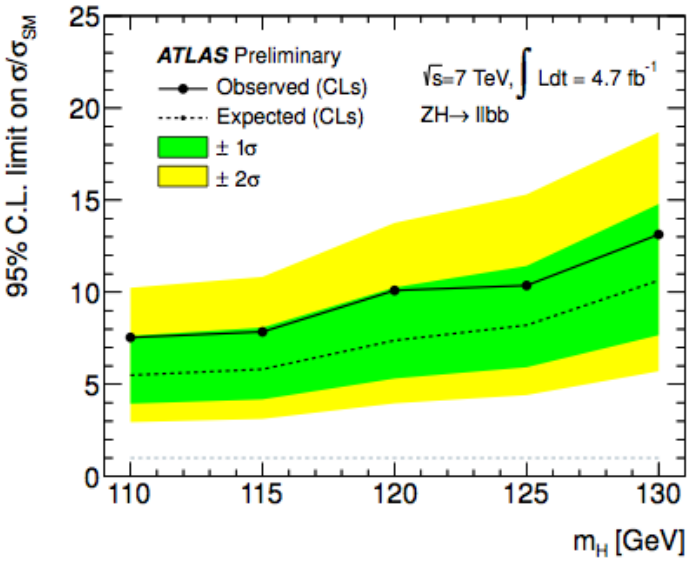


The vvbb Analysis

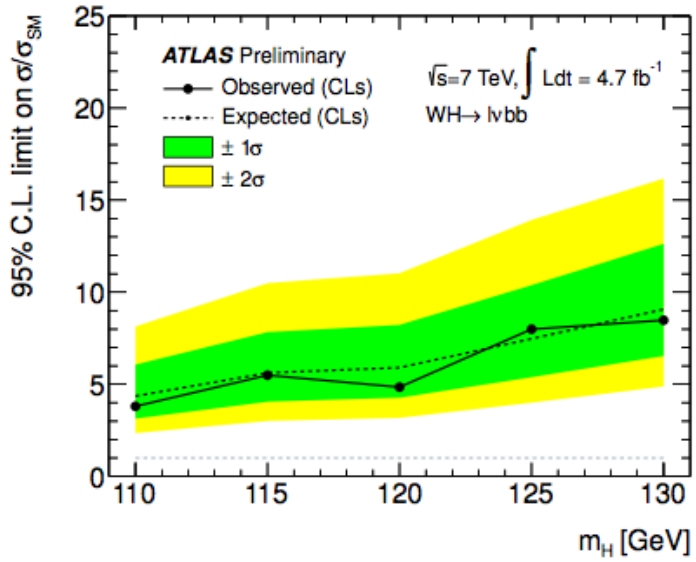


Bin	$ZH \to \ell^+\ell^- b\bar{b}$ p_T^Z[GeV]				$WH \to \ell\nu b\bar{b}$ p_T^W[GeV]				$ZH \to \nu\bar{\nu} b\bar{b}$ E_T^{miss}[GeV]		
	0-50	50-100	100-200	>200	0-50	50-100	100-200	>200	120-160	160-200	>200
Number of events for $80 < m_{b\bar{b}} < 150$ [GeV]											
Data	139	164	62	13	622	597	276	15	103	22	24
Signal	1.4 ± 0.2	2.0 ± 0.3	1.7 ± 0.3	0.4 ± 0.1	4.7 ± 0.9	5.2 ± 1.0	4.1 ± 0.9	1.4 ± 0.3	2.3 ± 0.5	1.3 ± 0.3	1.8 ± 0.5
Top	18	25	7	0	260	383	219	8.6	42	9	4
W+jets	-	-	-	-	285	181	72	12	13	7	4
Z+jets	132	126	58	5.6	0.4	0.3	0.1	0.0	33	12	7
Diboson	8	6	4	1	13	13	8	1	5	5	4
Multijet	-	-	-	-	64	42	4	1	1.2	0.2	0.4
Total Bkg	157 ± 15	157 ± 11	70 ± 7	6 ± 2	625 ± 36	620 ± 24	303 ± 13	23 ± 4	94 ± 10	33 ± 5	20 ± 5
Components of the Background Systematic Uncertainties [%]											
B-tag Eff	3.1	2.8	2.2	7.7	1.4	1.7	2.5	11.3	4.1	9.2	15.6
Bkg Norm	5.2	5.0	5.2	5.6	4.0	2.8	2.7	5.5	3.1	3.9	4.2
Jets/E_T^{miss}	1.0	2.8	3.5	3.1	2.1	1.6	1.6	6.4	8.2	10.7	16.9
Leptons	0.4	0.5	1.1	3.6	1.0	0.4	0.7	6.1	-	-	-
Luminosity	0.2	0.1	0.2	0.4	0.1	0.1	0.1	0.2	0.2	0.5	0.8
Pile Up	0.7	1.8	1.5	6.9	0.6	0.7	1.1	2.5	0.7	2.6	1.9
Theory	7.3	1.7	7.2	23.4	3.1	1.0	1.1	11.9	3.7	6.3	11.1
Total Bkg	9.6	6.9	10.0	26.6	5.8	3.9	4.4	19.6	10.4	16.1	26.0
Components of the Signal Systematic Uncertainties [%]											
B-tag Eff	10	11	13	16	10	11	13	15	13	16	21
JES/MET	6.5	4.6	4.0	3.7	6.7	6.8	7.8	4.7	11.0	5.4	9.9
Leptons	1.1	1.5	1.5	3.6	3.2	4.2	5.0	5.5	-	-	-
Luminosity	3.9	3.9	3.9	3.9	3.9	3.9	3.9	3.9	3.9	3.9	3.9
Pile Up	0.7	1.2	2.4	3.4	1.4	3.9	3.2	3.4	0.5	0.8	2.1
Theory	5	5	5	5	13	13	13	13	13	13	13
Total Signal	13.6	13.3	14.9	18.3	18.5	19.4	21.4	21.5	21.8	21.7	26.8

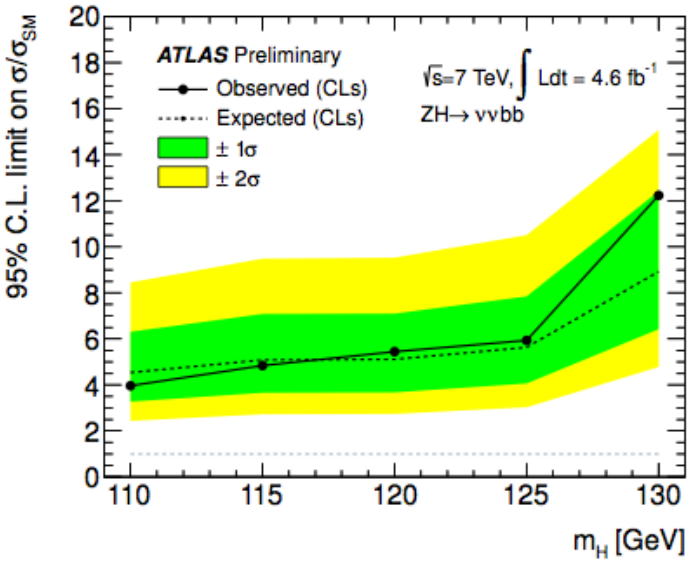
Results

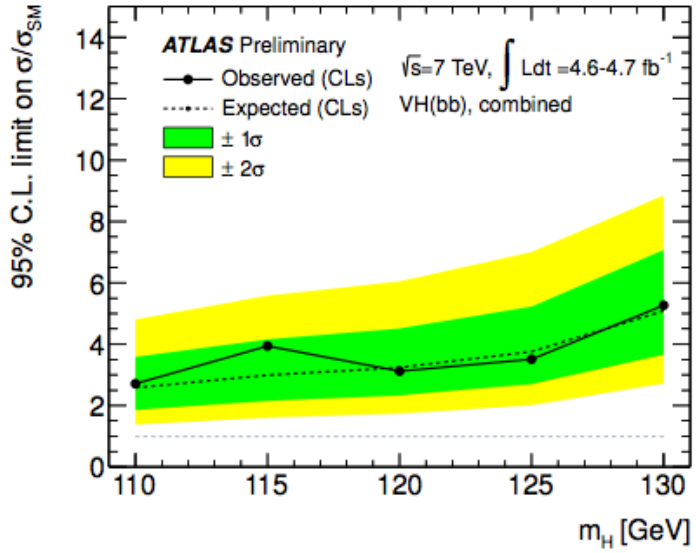

ATLAS Preliminary
Observed (CLs)
Expected (CLs)
± 1σ
± 2σ
√s=7 TeV, ∫ Ldt = 4.7 fb⁻¹
ZH→ llbb
95% C.L. limit on σ/σ_SM
m_H [GeV]

(a)


ATLAS Preliminary
Observed (CLs)
Expected (CLs)
± 1σ
± 2σ
√s=7 TeV, ∫ Ldt = 4.7 fb⁻¹
WH→ lνbb
95% C.L. limit on σ/σ_SM
m_H [GeV]

(b)


ATLAS Preliminary
Observed (CLs)
Expected (CLs)
± 1σ
± 2σ
√s=7 TeV, ∫ Ldt = 4.6 fb⁻¹
ZH→ ννbb
95% C.L. limit on σ/σ_SM
m_H [GeV]


ATLAS Preliminary
Observed (CLs)
Expected (CLs)
± 1σ
± 2σ
√s=7 TeV, ∫ Ldt =4.6-4.7 fb⁻¹
VH(bb), combined
95% C.L. limit on σ/σ_SM
m_H [GeV]

Conclusions and Outlook

- The search for the Higgs boson in the bb channel in the associated production is now a sensitive channel especially in the very low mass range where it reaches a 95% CL exclusion sensitivity of μ^{95} = 2.6 (up to 5.1 at higher mass hypotheses) the observed limits range from 2.7 to 5.3.

- No significant excess is observed in this channel.

- There is still room for improvement (substructure).

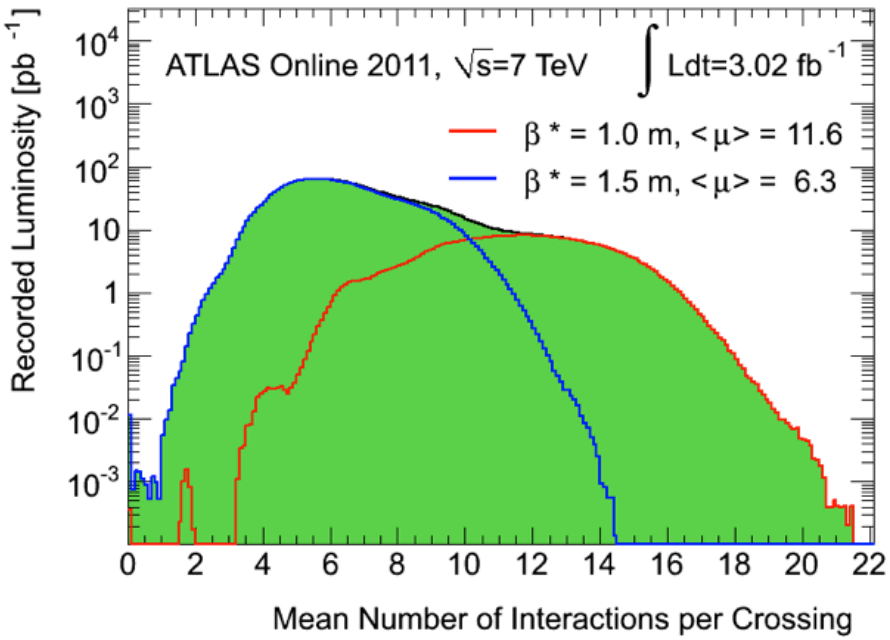
- Of course… the overall picture is still consistent.

Backup

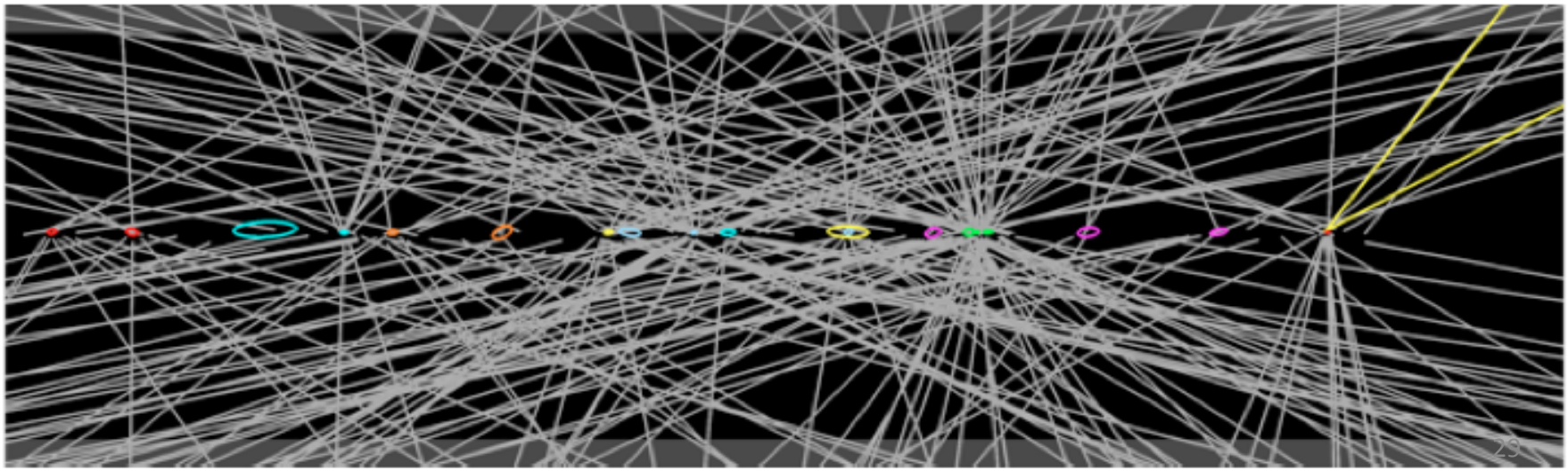
The 2011 Dataset

$$5.6\,fb^{-1}$$

Delivered Luminosity



Recent event with 15 Vertices



Luminosity and Beam cross section

$$\mathcal{L} = \frac{N_p^2 k_b f_{rev} \gamma}{4\pi\beta^* \epsilon_n} F$$

Reduction factor W/ Beam crossing angle O(0.9)

Parameter	2010	2011	Nominal
N(10^{11} p/bunch)	1.2	1.35	1.15
k (N bunches)	368	1380	2808
Bunch spacing	150	50	25
ε (μm rad)	2.4-4	1.9-2.3	3.75
β* (m)	3.5	1.5-1	0.55
L ($cm^{-2}s^{-1}$)	$2x10^{32}$	$3.3x10^{33}$	10^{34}

Beam parameters close to nominal in terms of luminosity

What Next? 8 TeV

~ 10% improvement in sensitivity

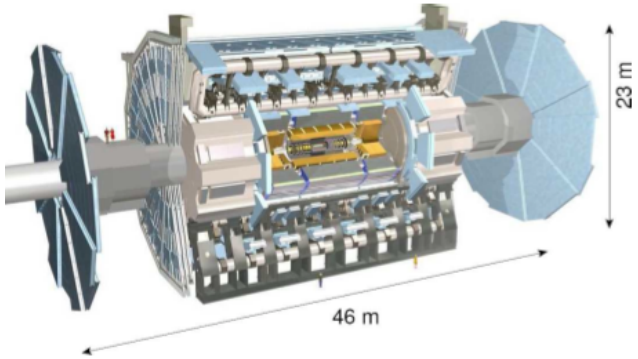
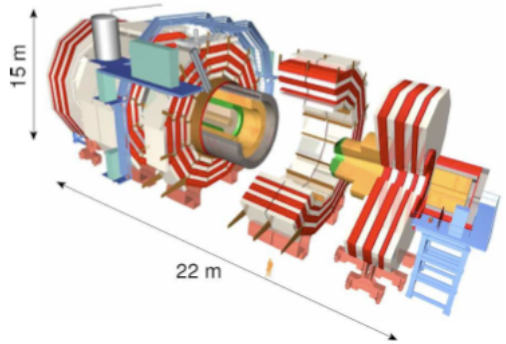
Parameter	2010	2011	2012	Nominal
k (N bunches)	368	1380	1380	2808
Bunch spacing	150	50	50	25
ε (μm rad)	2.4-4	1.9-2.3	2.5	3.75
β^* (m)	3.5	1.5-1	0.6	0.55
L ($cm^{-2}s^{-1}$)	$2x10^{32}$	$3.3x10^{33}$	$\sim 7x10^{33}$	10^{34}

More O(30) PU events!

- In 2012 ~20 fb^{-1} : Foresee O(7) fb^{-1} for ICHEP
  - Confirm (5σ sensitivity)
  - Infirm (exclude at 95% CL with such a large excess)
- Next LS1 preparing for higher energies >12 TeV

2012 Should bring a definite answer to the search of the SM Higgs boson

The ATLAS and CMS Detectors In a Nutshell

Sub System	ATLAS	CMS
Design		
Magnet(s)	Solenoid (within EM Calo) 2T 3 Air-core Toroids	Solenoid 3.8T Calorimeters Inside
Inner Tracking	Pixels, Si-strips, TRT PID w/ TRT and dE/dx $\sigma_{p_T}/p_T \sim 5 \times 10^{-4} p_T \oplus 0.01$	Pixels and Si-strips PID w/ dE/dx $\sigma_{p_T}/p_T \sim 1.5 \times 10^{-4} p_T \oplus 0.005$
EM Calorimeter	Lead-Larg Sampling w/ longitudinal segmentation $\sigma_E/E \sim 10\%/\sqrt{E} \oplus 0.007$	Lead-Tungstate Crys. Homogeneous w/o longitudinal segmentation $\sigma_E/E \sim 3\%/\sqrt{E} \oplus 0.5\%$
Hadronic Calorimeter	Fe-Scint. & Cu-Larg (fwd) $\gtrsim 11\lambda_0$ $\sigma_E/E \sim 50\%/\sqrt{E} \oplus 0.03$	Brass-scint. $\gtrsim 7\lambda_0$ Tail Catcher $\sigma_E/E \sim 100\%/\sqrt{E} \oplus 0.05$
Muon Spectrometer System Acc. ATLAS 2.7 & CMS 2.4	Instrumented Air Core (std. alone) $\sigma_{p_T}/p_T \sim 4\,\%$ (at 50 GeV) $\sim 11\,\%$ (at 1 TeV)	Instrumented Iron return yoke $\sigma_{p_T}/p_T \sim 1\%$ (at 50 GeV) $\sim 10\%$ (at 1 TeV)