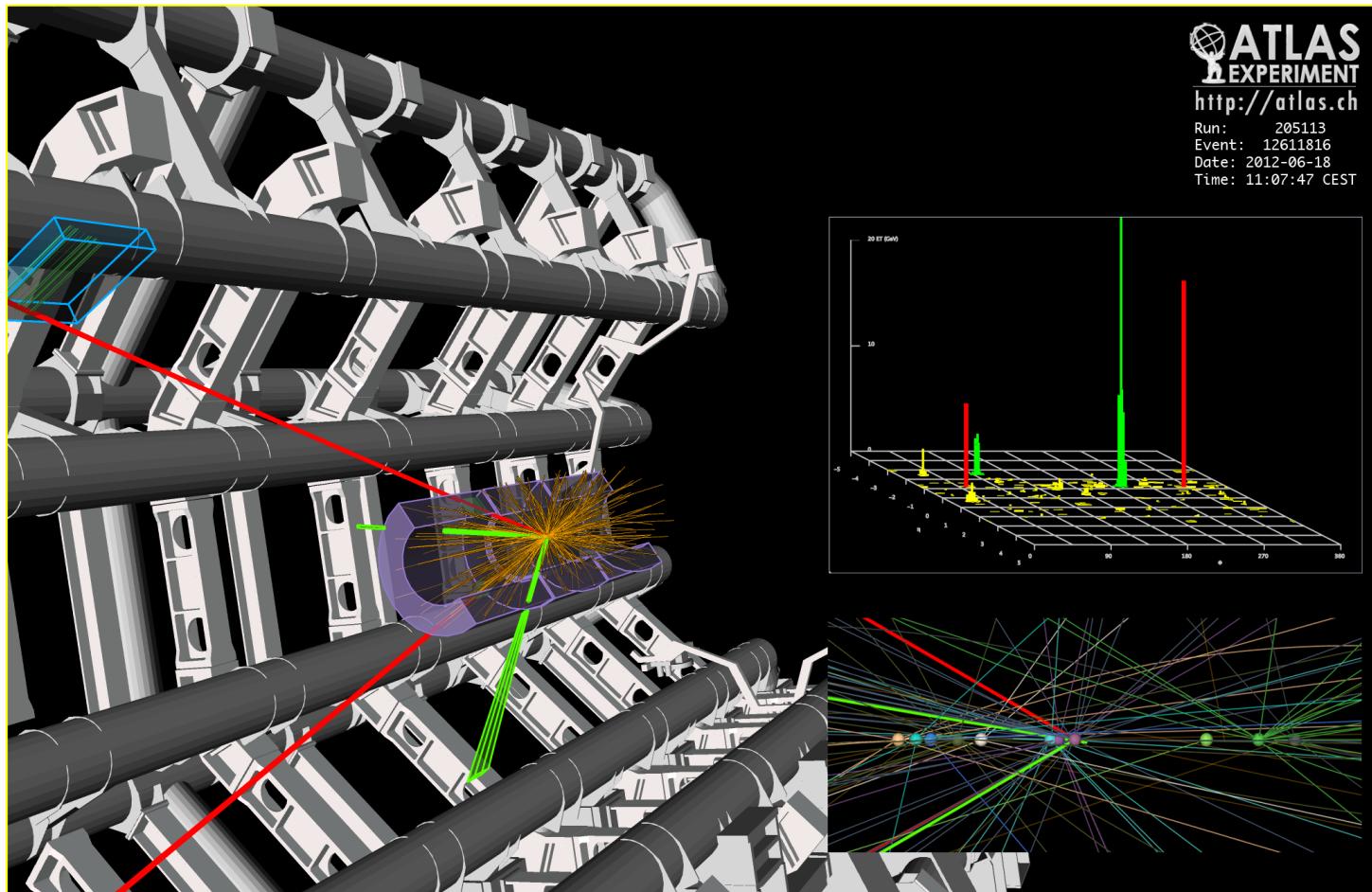


Atlas highlights at ICHEP 2012

Bruno Mansoulié (CEA-IRFU-Saclay)

On behalf of the Atlas collaboration



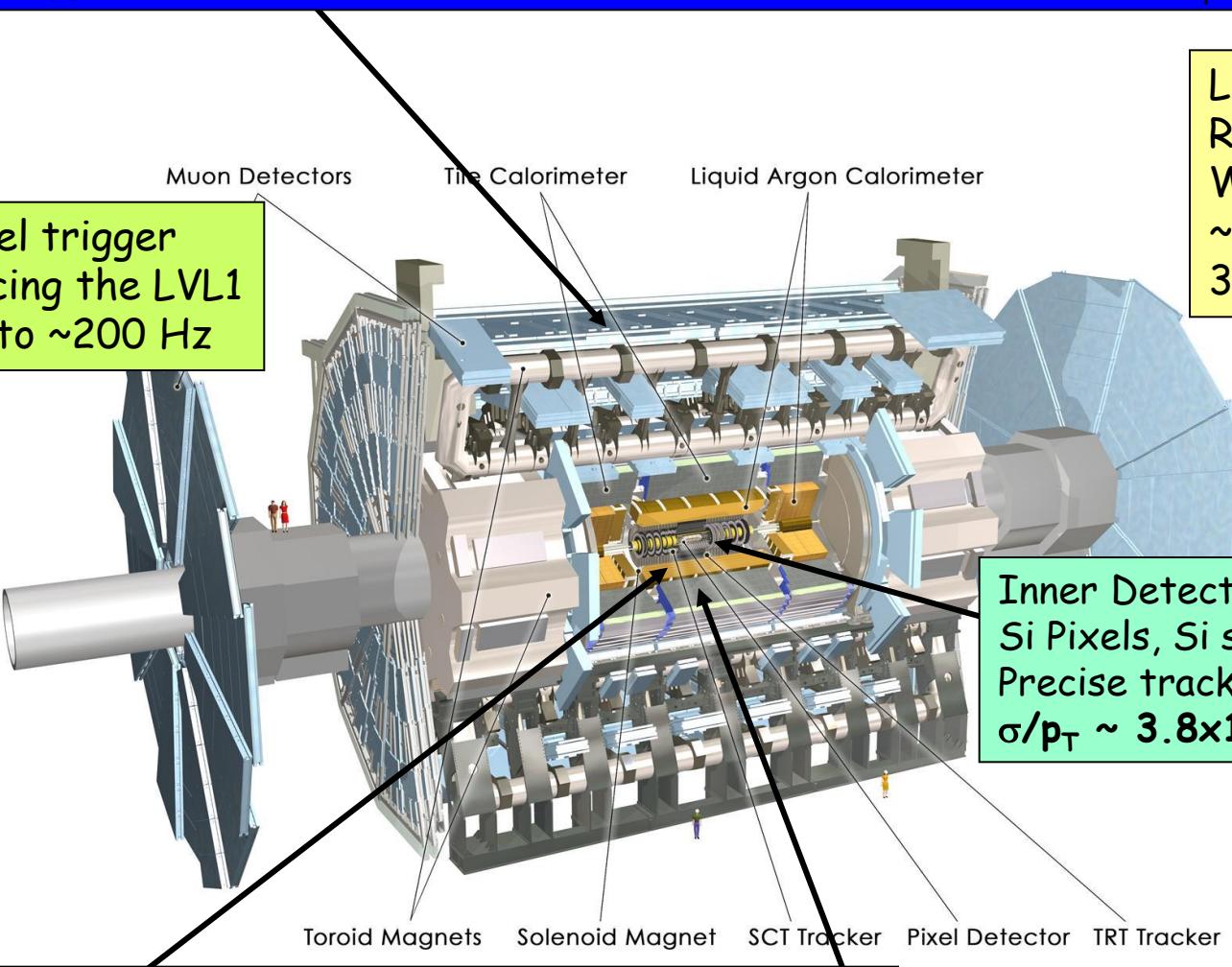
Contents

- **The Atlas detector**
- **Data in 2012**
 - Luminosity, Data taking & quality, trigger
 - Physics objects optimization
- **Physics analyses and results**

(personal choice from 66 Atlas talks and 7 posters!)

 - **Standard Model**
 - W , di-bosons
 - **Beyond Standard Model**
 - di-jets, di-leptons, di-photons, di-tops
 - Susy: light s-top
 - **Standard Model Higgs search**
 - $H\gamma\gamma$, $H4l$
 - Combination

Muon Spectrometer ($|\eta| < 2.7$) : air-core toroids with gas-based muon chambers
Muon trigger and measurement with momentum resolution $< 10\%$ up to $E_\mu \sim 1$ TeV



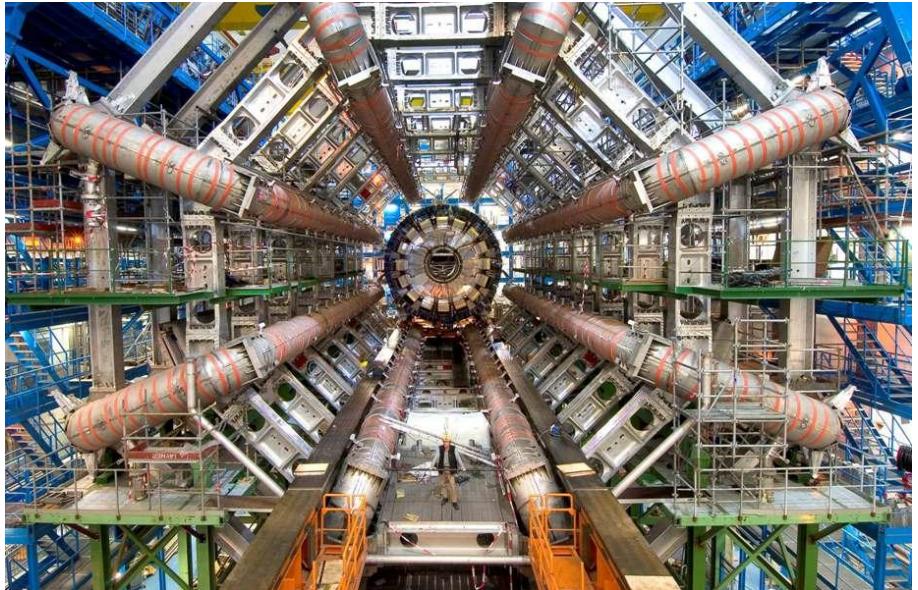
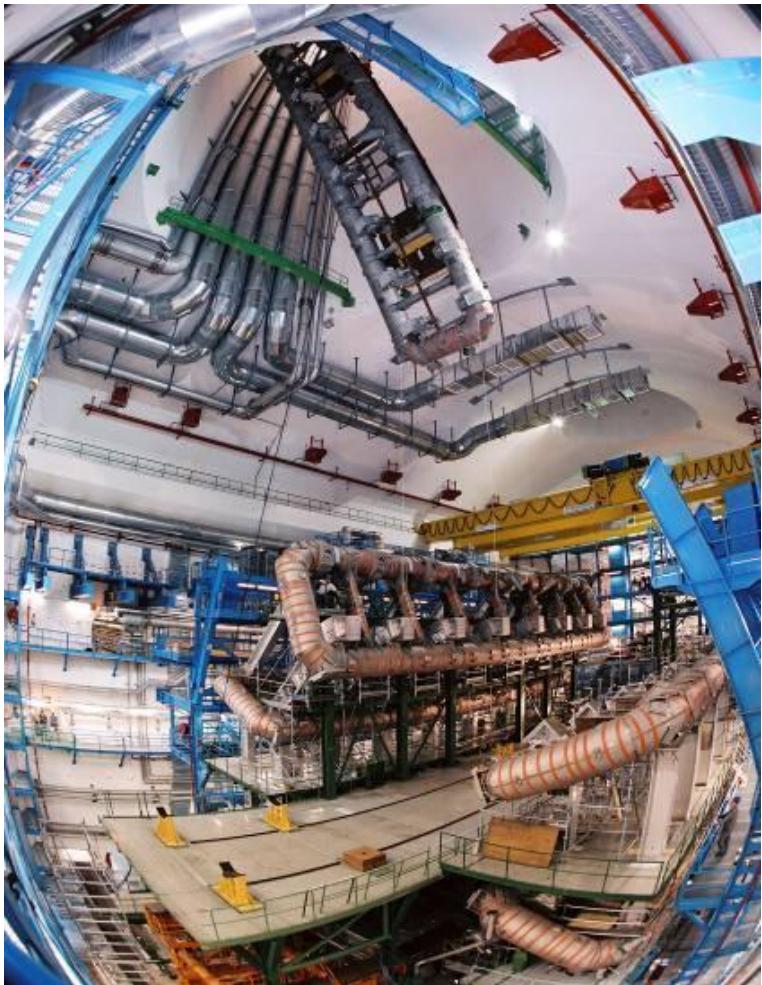
Length : ~ 46 m
Radius : ~ 12 m
Weight : ~ 7000 tons
 $\sim 10^8$ electronic channels
3000 km of cables

Inner Detector ($|\eta| < 2.5$, $B=2T$):
Si Pixels, Si strips, TRT
Precise tracking and vertexing,
 $\sigma/p_T \sim 3.8 \times 10^{-4} p_T (\text{GeV}) + 0.015$

EM calorimeter: Pb-LAr Accordion
 e/γ trigger, identification and measurement
E-resolution: $\sigma/E \sim 10\%/\sqrt{E} + 0.007$
granularity : $.025 \times .025 \oplus$ strips

HAD calorimetry ($|\eta| < 3$): segmentation 0.1×0.1
Fe/scintillator Tiles (central), Cu/W-LAr (fwd)
E-resolution: $\sigma/E \sim 50\%/\sqrt{E} + 0.03$
FWD calorimetry: W/LAr $\sigma/E \sim 90\%/\sqrt{E} + 0.07$

Remembering the detector construction: The barrel muon spectrometer

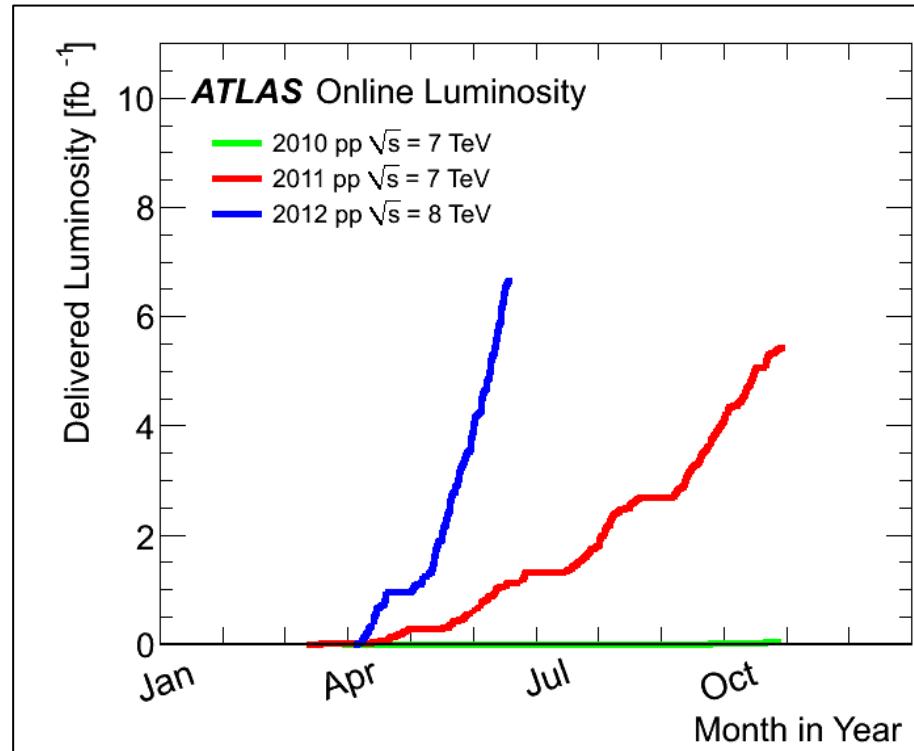


Construction: The Liquid argon ElectroMagnetic calorimeter



Data-taking

- **2010: 50 pb^{-1} at 7 TeV**
- **2011: 5.6 fb^{-1} at 7 TeV**
- **2012: 6.6 fb^{-1} at 8 TeV**
- **Peak L (2012): $6.8 \cdot 10^{33} \text{ cm}^{-2}\text{s}^{-1}$**

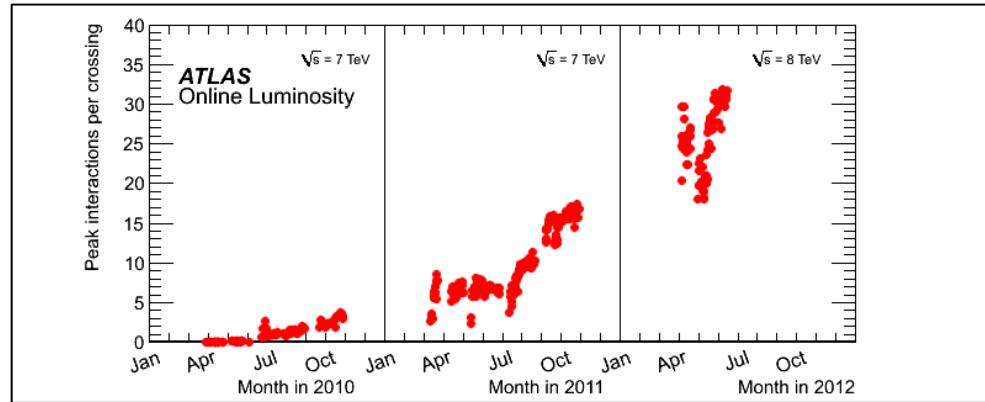


- More than $\sim 90\%$ of collisions delivered are used in the analysis (including experiment-ready and data-quality)
- Most sub-detectors operational at the 99.9% level

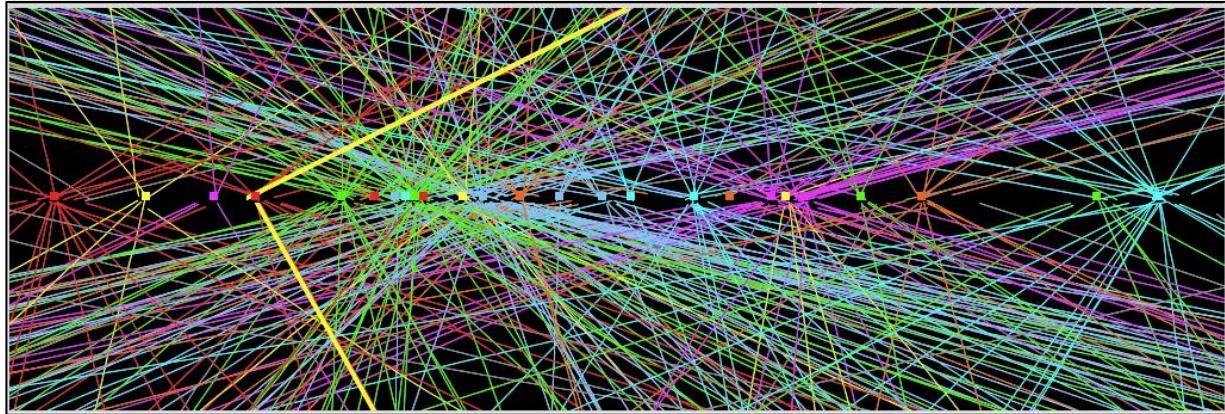
Pile-up

- Bunch spacing 50ns instead of 25ns:
2x collisions/bunch crossing

Presently: ~30 collisions/bunch-crossing



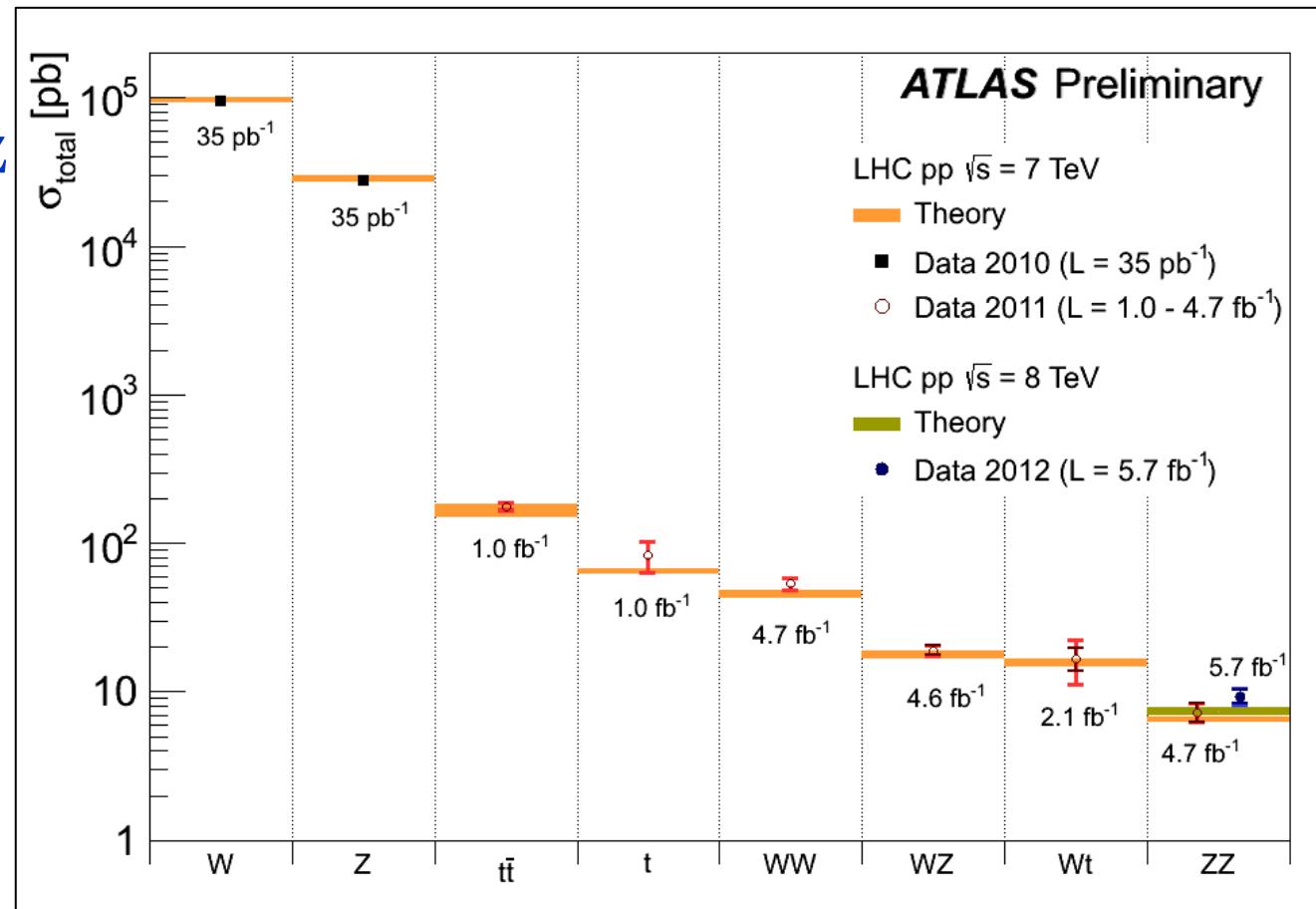
$Z \rightarrow \mu\mu$
+ 24 other
interactions
(min bias)



- Has to be fought and mitigated at all levels:
 - Trigger, reconstruction of physics objects, isolation cuts, etc.
 - Data processing: CPU time for reconstruction...

Standard Model Cross-sections (Barreiro)

- From inclusive W,Z down to ZZ
- Important tests of the SM
- Important also as backgrounds to Higgs searches



- Irreducible (ex: ZZ)
- Reducible (ex: W+ jets, t t...)

W and Z bosons

- Enormous number of W's ($\sim 10^8$) and Z's ($\sim 10^7$).

- Heavily used for calibration

$Z \rightarrow ee, W \rightarrow ev (E/p)$

- But also nice physics

– Ex: Tau polarization (*Demers*)

V-A coupling: τ polarized, can be measured in the τ decay

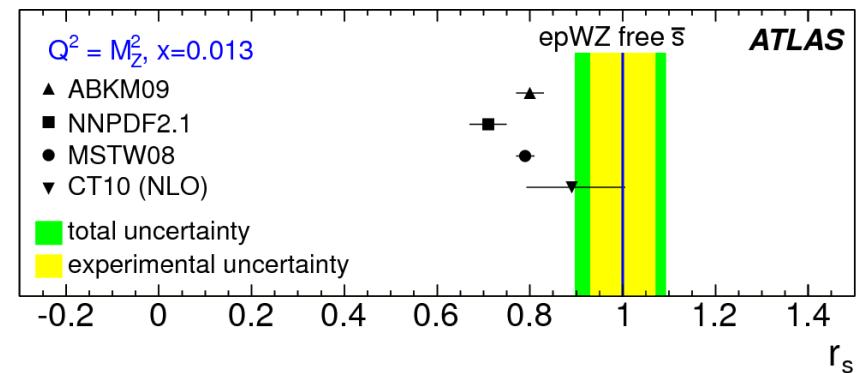
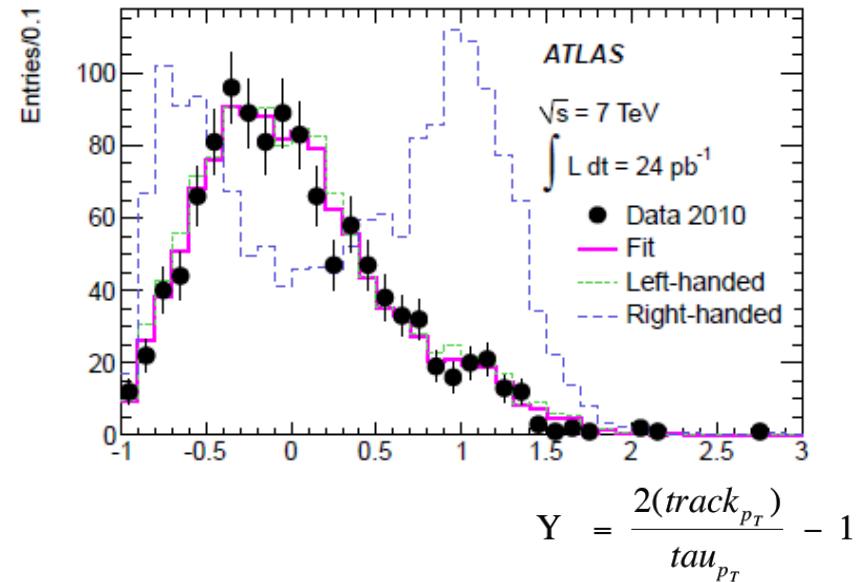
– Strange quark density in proton

(*Boonekamp*)

from W, Z longitudinal distribution

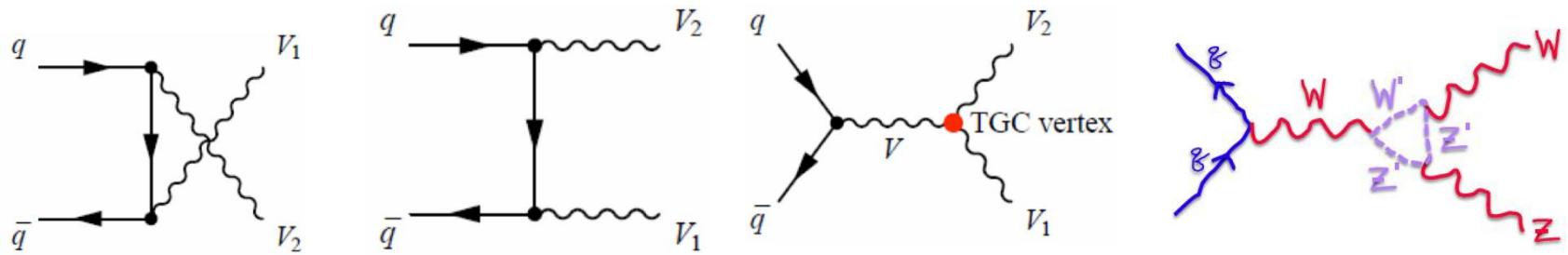
\Rightarrow sea-quarks flavor independence

(sea- s = sea- d)



Di-bosons

- Tests of the Standard Model
- Background for other searches, in particular Higgs
- Probe New Physics



- New Physics parametrized by effective Lagrangian Triple Gauge Couplings
 - Modify rate and p_T distribution

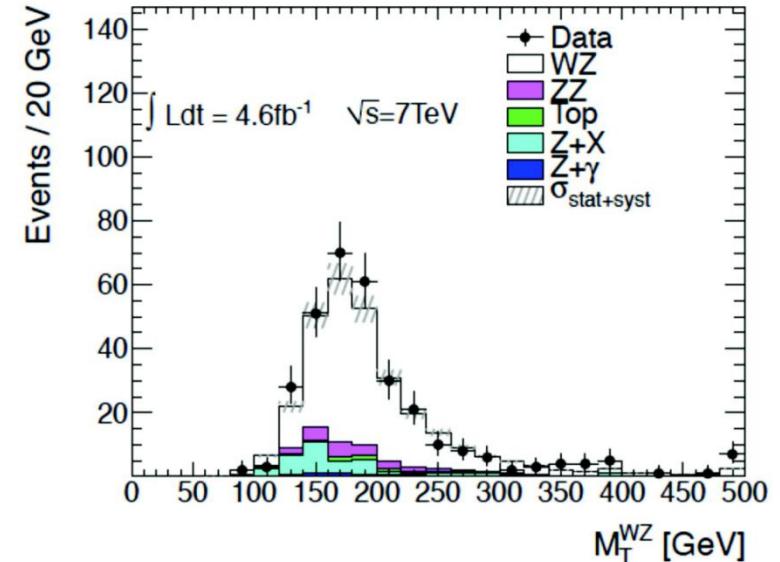
coupling	parameters	channel
$WW\gamma$	$\lambda_\gamma, \Delta\kappa_\gamma$	$WW, W\gamma$
WWZ	$\lambda_Z, \Delta\kappa_Z, \Delta g_1^Z$	WW, WZ
$ZZ\gamma$	h_3^γ, h_4^γ	$Z\gamma$
$Z\gamma\gamma$	h_3^γ, h_4^γ	$Z\gamma$
$Z\gamma Z$	f_{40}^Z, f_{50}^Z	ZZ
ZZZ	$f_{40}^\gamma, f_{50}^\gamma$	ZZ

Di-bosons: $W + Z$, $W/Z + \gamma$

- $W + Z$ (*Hays; also WW and ZZ*)

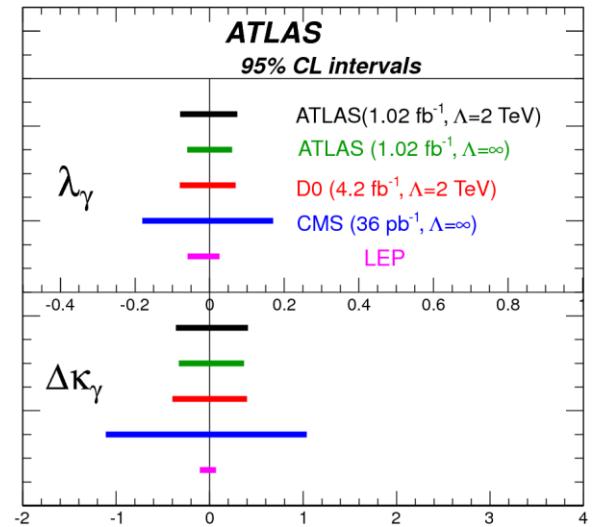
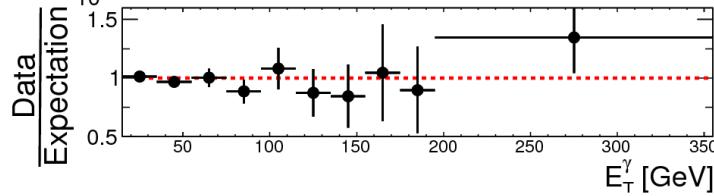
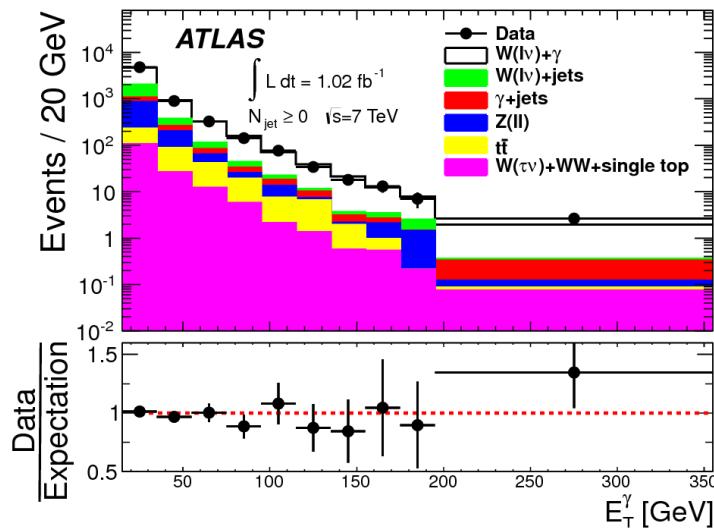
$$\sigma(WZ) = 19.0^{+1.4}_{-1.3} \text{ (stat)} \pm 0.8 \text{ (syst)} \pm 0.4 \text{ (lumi)}$$

$$\sigma(WZ) \text{ SM (NLO)} = 17.6^{+1.1}_{-1.0}$$

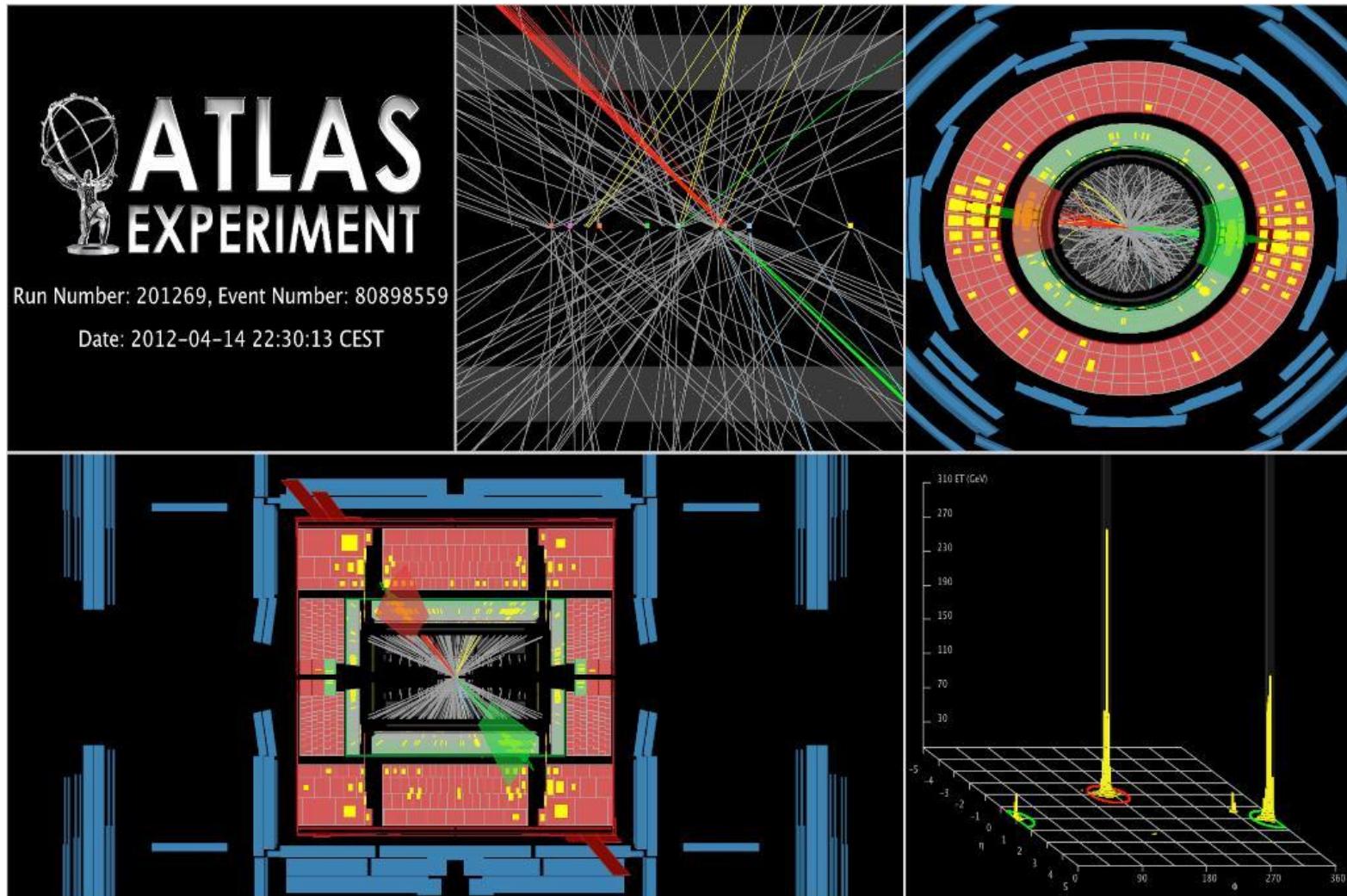


- $W + \gamma$ (*Han*)

Limits on
anomalous couplings

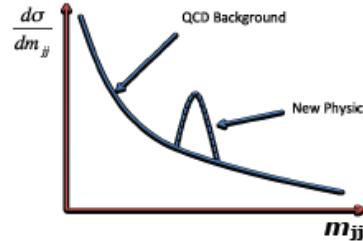


Dijets and dijet searches

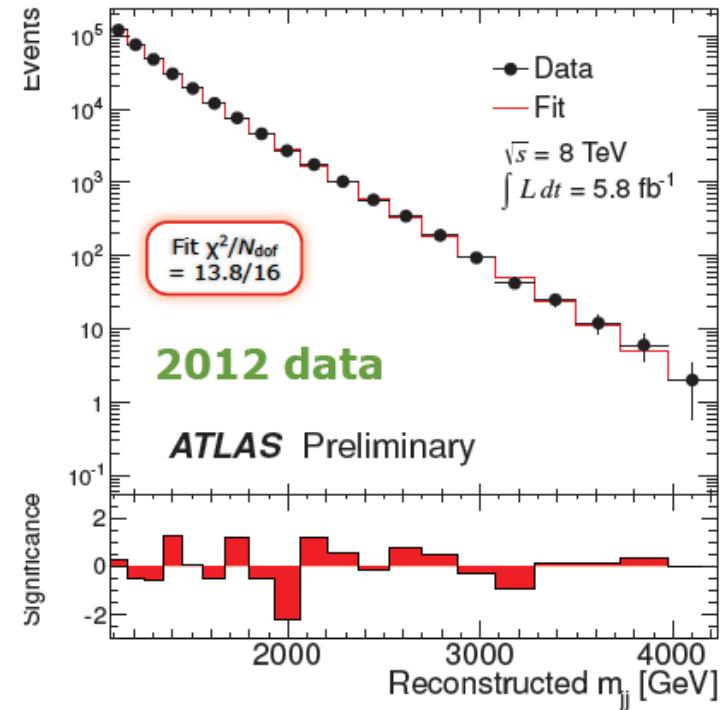


Dijets and dijet searches (*Gillbert*)

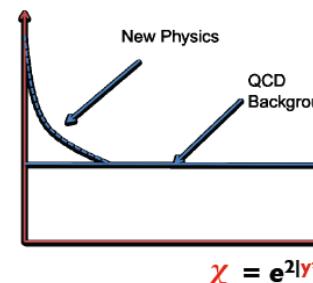
- Dijets : probe of highest masses
- Events with more than 4 TeV m_{jj}



- Look for bumps
($q^* \dots$)



- Look for angular deviation from QCD scattering (Rutherford)



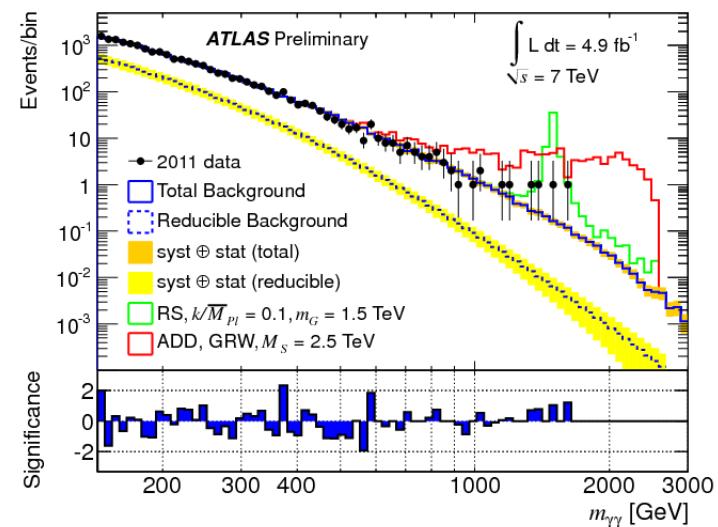
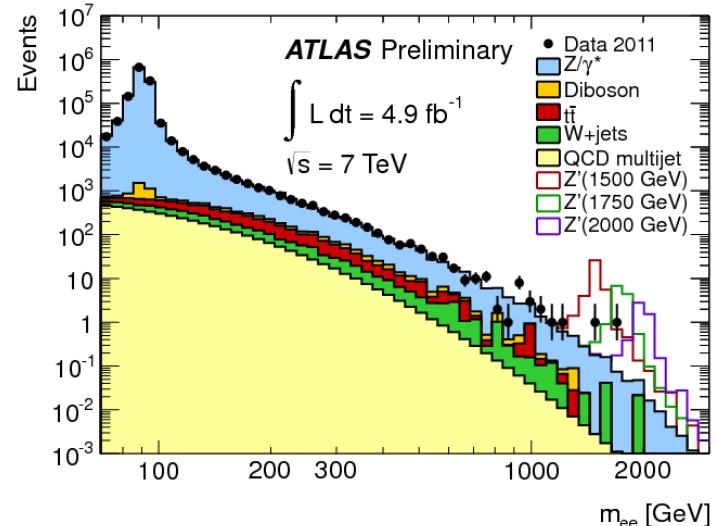
- Limits: $m(q^*) > 3.66$ TeV; L (contact interaction) > 7.6 TeV
Black Holes, Extra-dim, etc.

Di-leptons, $\gamma\gamma$ resonances (*Anduaga*)

- $e e$ or $\mu \mu$ resonance search
 - Z' (spin 1) : typically $U(1)$ left over from grand-unified group breakdown
 - G^* (spin 2): extra-dim theories:
Kaluza-Klein excitation of graviton

Typical limit : $m(Z'_{SSM}) > 2.21$ TeV
 $m(G^*) > 2.16$ TeV [$k/M_{Pl} = 0.1$]

- $\gamma\gamma$ searches: search for extra-dimensions
 - G^* (Randall-Sundrum): resonance
 $M(G^*) > 2.06$ TeV [$k/M = 0.1$]
 - ADD: high mass deviation
 $M_S > [2.5 - 3.9$ TeV]

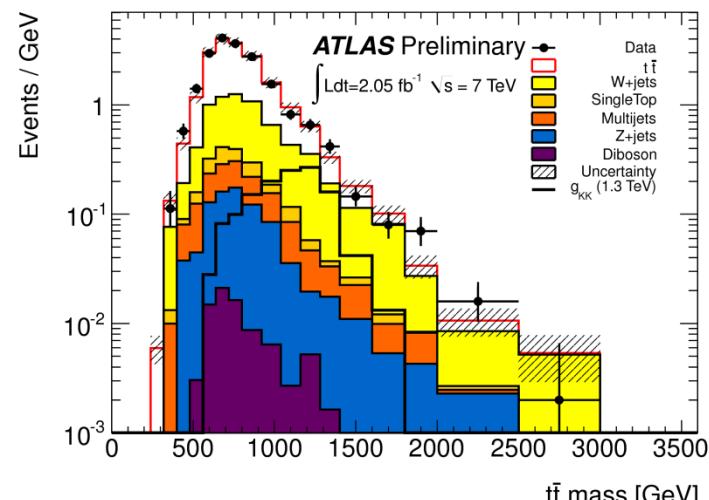
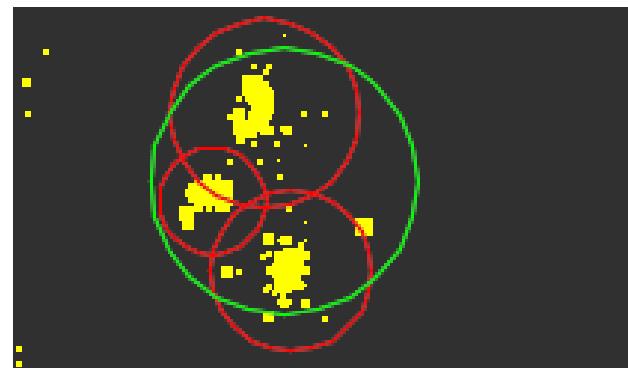
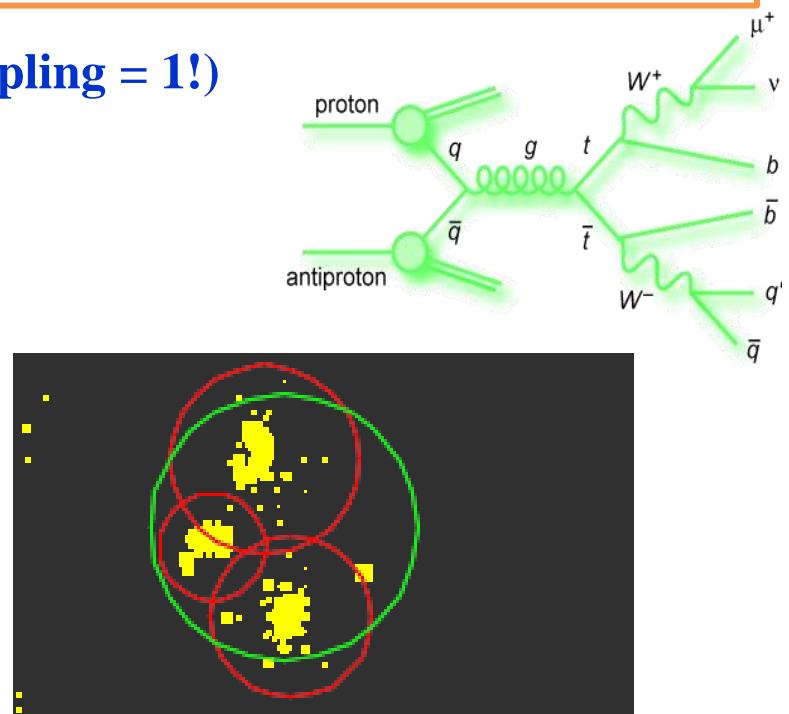


t t resonances (V_{os})

- Top quark : special in the SM (Yukawa coupling = 1!)
 => Beyond SM top-physics very fashionable
 simplest search mode : t t resonance

- Top decay: W + b ; W decay: lν or q q'

- Lepton + jets mode
 - Classical : second top seen in 3 jets
 - Limited at high mass
 - Boosted top: high p_T top seen as *fat jet*
 - Normal jet algorithm: 1 jet
 - Special boosted top algorithm: 3 jets in 1
 - Limit on a Kaluza-Klein Gluon:
 $m > 1.5 \text{ TeV}$



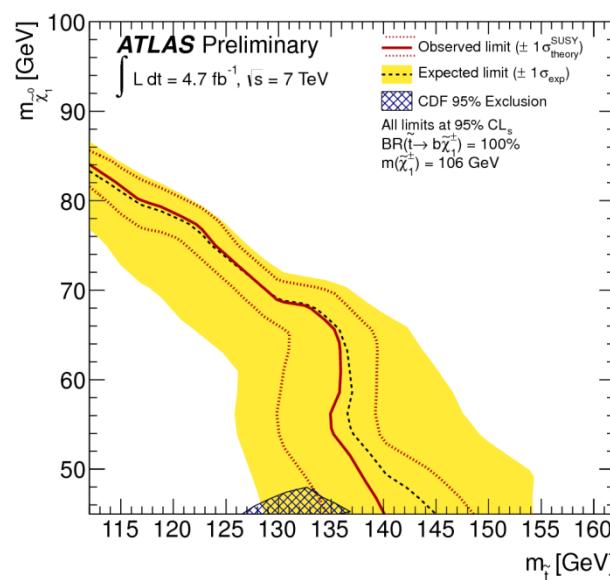
Supersymmetry: search for light s-top (J. White)

- In many models with unified scalar masses at high mass, the s-top can be light (even lighter than the top)
- Typical process: stop-stop production

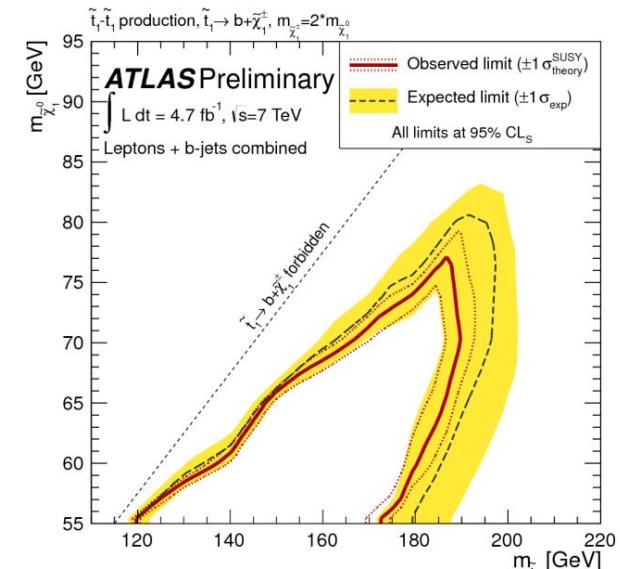
$$\tilde{t}_1 \rightarrow b\tilde{\chi}_1^\pm \\ \tilde{\chi}_1^\pm \rightarrow W^{(*)}\tilde{\chi}_1^0$$

search in $l_1 l_2 + \text{jet}$
or $l + b\text{-jet}$
gives access to different
orderings of masses

7 TeV , 4.7 fb⁻¹



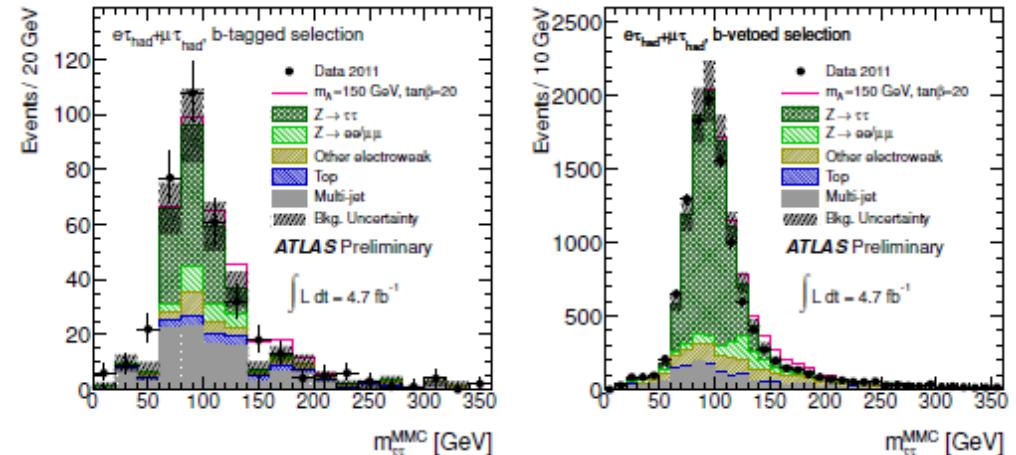
$$m(\chi_1^\pm) = 106 \text{ GeV} \\ m(\text{stop}) \ll m(\text{top})$$



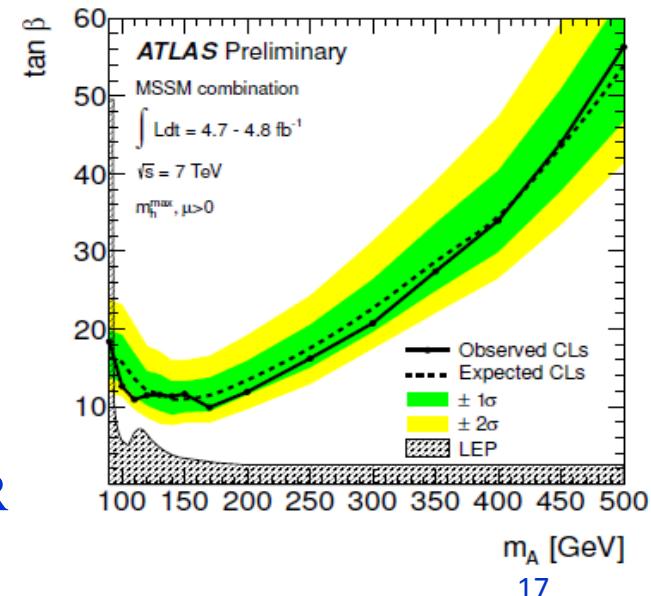
$$m(\chi_1^\pm) = 2 m(\chi_1^0) \\ m(\text{stop}) \sim m(\text{top})$$

MSSM Higgs search (Thoma)

- 7 TeV (2011) data
- MSSM: 3 neutral Higgs bosons:
h, H and A
 - Production via gluon fusion and b-quark annihilation
(coupling to b increases with $\tan\beta$)
 - Decay bb (90%), $\tau^+\tau^-$ (10%), $\mu^+\mu^-$ (0.04%)
- Search in $\mu^+\mu^-$ and $\tau^+\tau^-$
 - $\mu\mu$: good mass resolution, but low rates
 - $\tau\tau$: Similar to SM $H \rightarrow \tau\tau$: lepton/hadron categories
 - use b-tagged/b-vetoed selections (different S/B)
- Limits in $(m_A, \tan\beta)$ plane and generically on $\sigma \cdot BR$

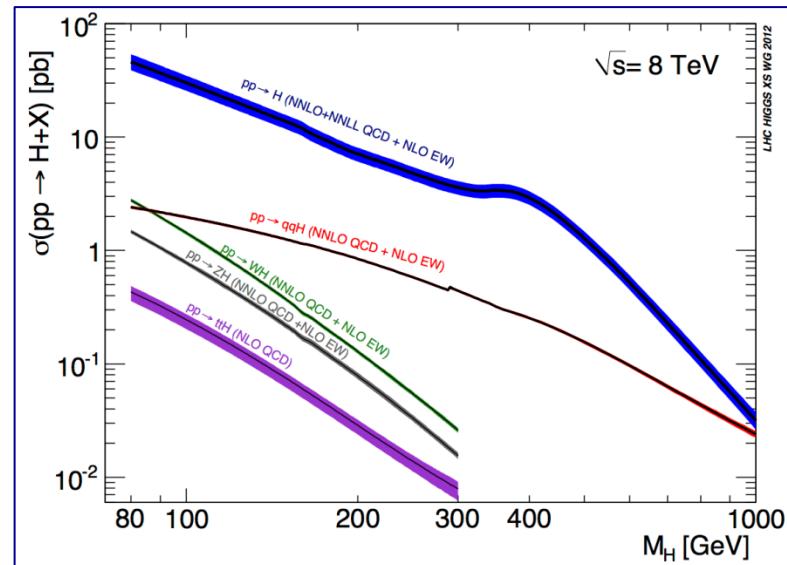
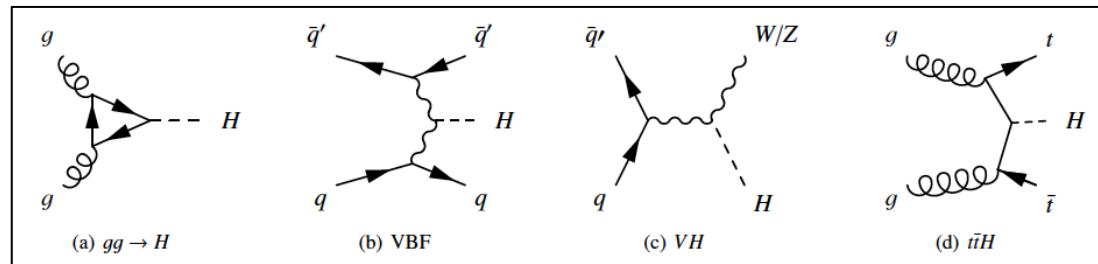


$\tau_{\text{lep}} \tau_{\text{had}}$ channels



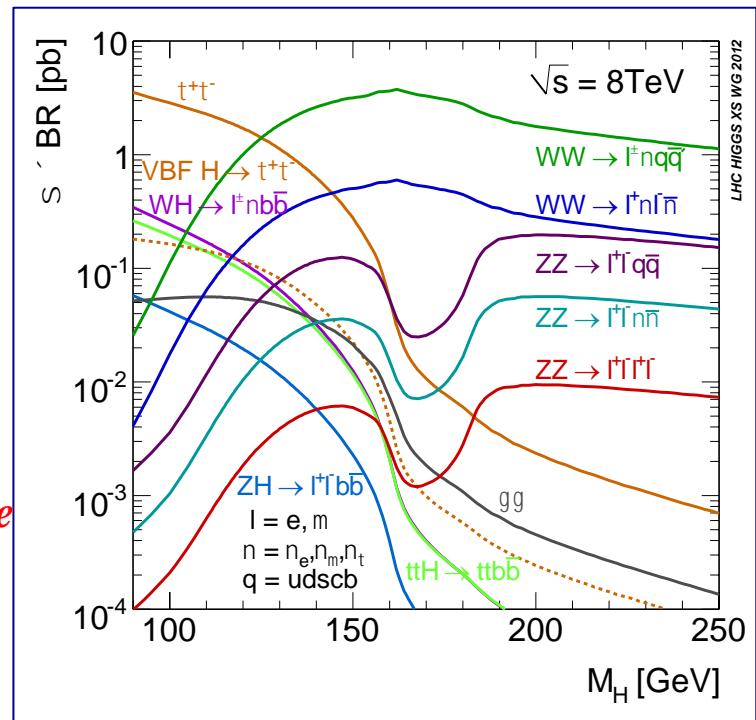
SM Higgs search (*Fabiola Gianotti, CERN July 4th seminar*)

- **Higgs production**
 - Gluon fusion
 - Vector Boson fusion
 - Associated
- Calculated at NLO/NNLO
- 2011: 7 TeV
- 2012: 8 TeV
- 7 TeV \Rightarrow 8 TeV: cross-section increases: ~ 1.3 for $m(H) = 125$ GeV
 - Similar increase for irreducible backgrounds : $\gamma\gamma$, ZZ, WW
 - Larger increase for reducible bkds: tt, Zbb, QCD...



SM Higgs decay modes

- Decay modes at $m(H) = 125$ GeV
 - $\gamma \gamma$ *High-resolution, High-significance*
 - 2 high p_T photons, $\sigma(m) \sim 2$ GeV
 - $Z Z^* \rightarrow 4l (e, \mu)$ “ “
 - electrons, muons, $\sigma(m) \sim 2$ GeV
 - $WW \rightarrow (e, \nu), (\mu, \nu)$ *Low-resol, High-significance*
 - 2 neutrinos; $\sigma(m) \sim 30$ GeV
 - $\tau \tau$ *Medium-resolution, low-significance*
 - n neutrinos; $\sigma(m) \sim 20$ GeV
 - $W/Z + H \rightarrow bb$ *Medium-resolution, low-significance*
 - 2 b-jets $\sigma(m) \sim 16$ GeV
- For higher masses: $WW \rightarrow llqq'$, $ZZ \rightarrow llvv$, $ZZ \rightarrow llqq$

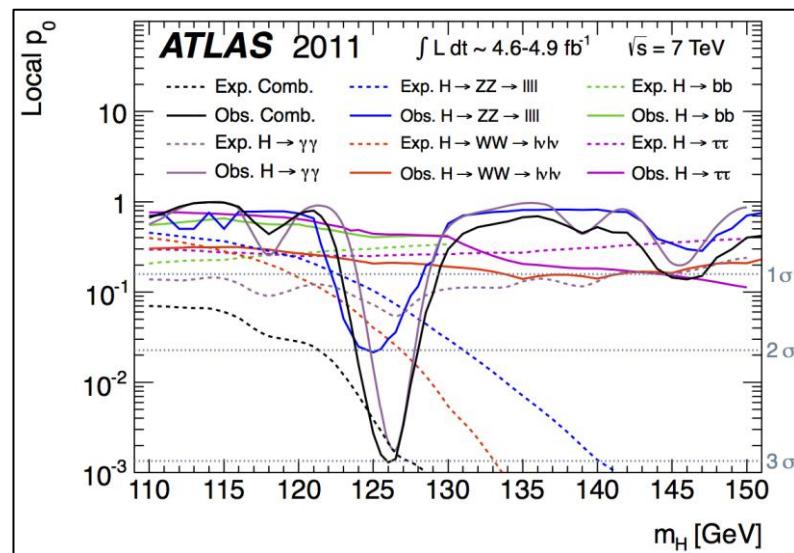
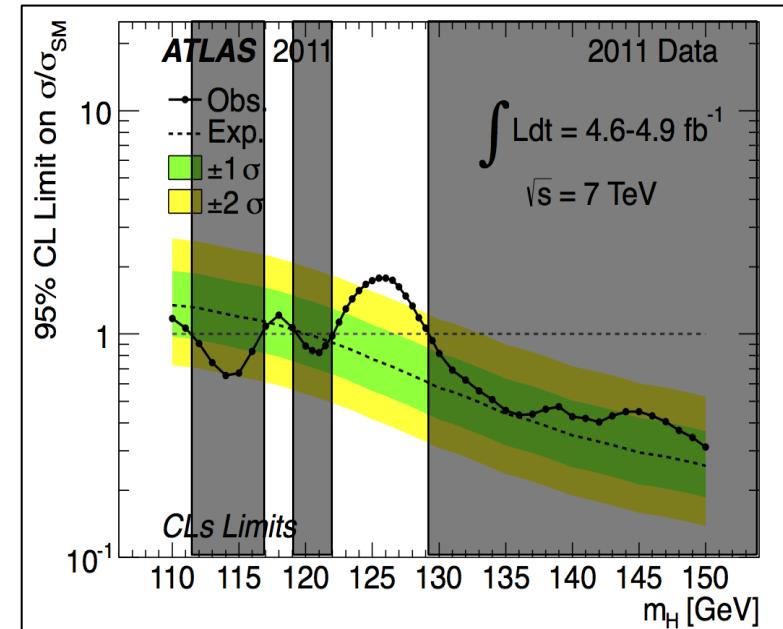


SM Higgs: Results from 2011 data

Combination of 12 channels:

- $H \rightarrow \gamma\gamma$
- $W/ZH \rightarrow W/Z b\bar{b}$ (3 final states)
- $H \rightarrow \tau\tau$ (3 final states)
- $H \rightarrow ZZ^{(*)} \rightarrow 4l$
- $H \rightarrow WW^{(*)} \rightarrow llvv$
- $H \rightarrow ZZ \rightarrow llqq$
- $H \rightarrow ZZ \rightarrow llvv$
- $H \rightarrow WW \rightarrow lvqq$

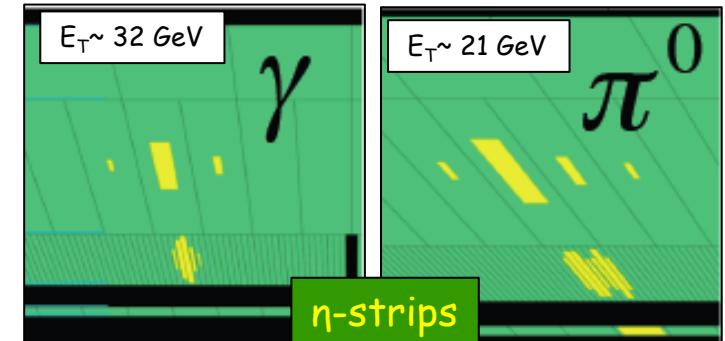
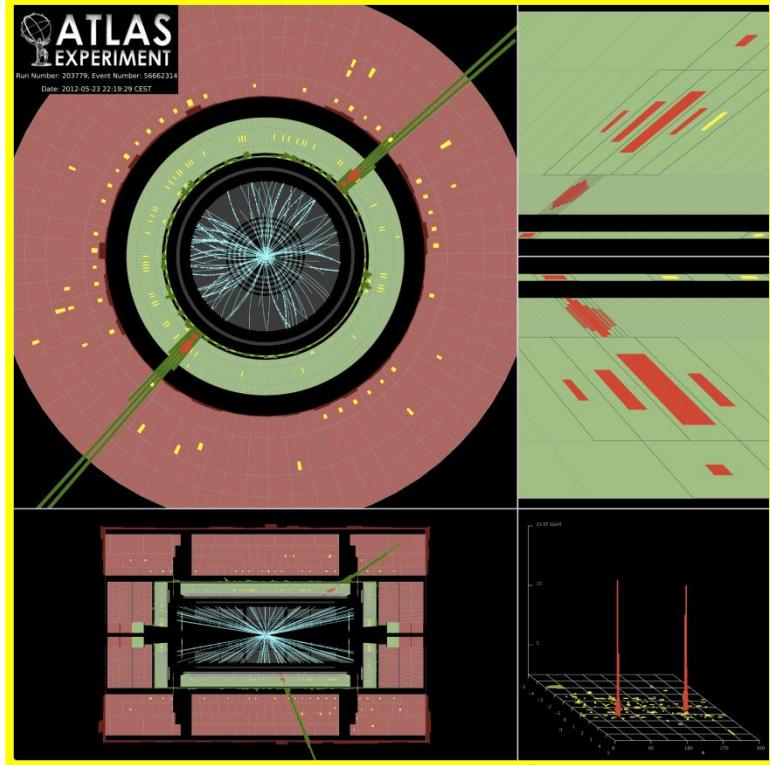
- Excluded: 111.4- 541GeV except:
 - 116.6 -119.4 (as expected from background)
 - 122.1- 129.2 (significant excess)
- Excess at ~126 GeV
 - 2.9 σ local
 - 15 % global probability



Higgs $\rightarrow \gamma\gamma$ (Tackmann)

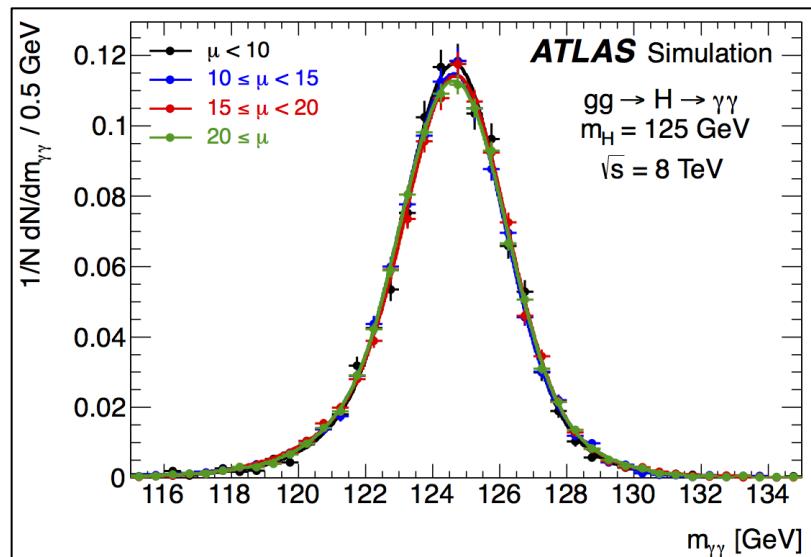
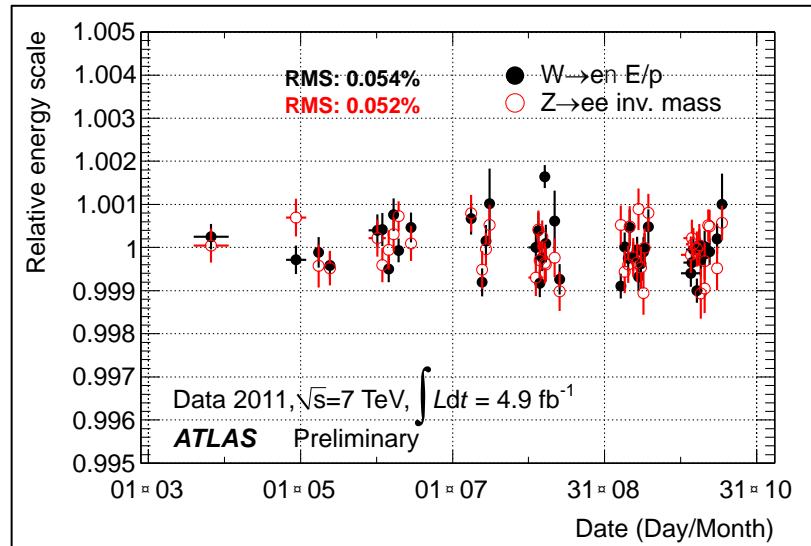
- 2011 + 2012 data
- 2 high- p_T , isolated photons (40, 30 GeV)
- Use fine granularity of the EM calorimeter in particular first longitudinal sampling
 - photon direction
 - Pileup/ vertex determination
 - Vertex $z \Leftrightarrow$ mass resolution
 - photon identification
 - Rejection of jets/ π^0

Reducible background : QCD γ -jet, jet-jet reduced to $\sim 20\%$ of irreducible QCD $\gamma\gamma$



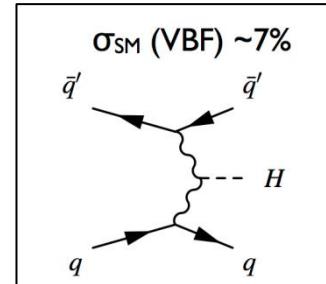
H_{γγ}: photon energy measurement

- Photon energy scale
 - derived from electrons
 - $Z \rightarrow ee$, $W \rightarrow ev$, $J/\psi \rightarrow ee$
 - uniformity
 - ~1% for η [0, 1.35] and [1.8, 2.4]
 - ~2.5% for η [1.35, 1.8]
 - stability better than 0.1 %
- Mass resolution
 - Insensitive to pileup
 - typically $\sigma = 1.6$ GeV
 - reduced ‘tails’: 90% signal in $\pm 2\sigma$



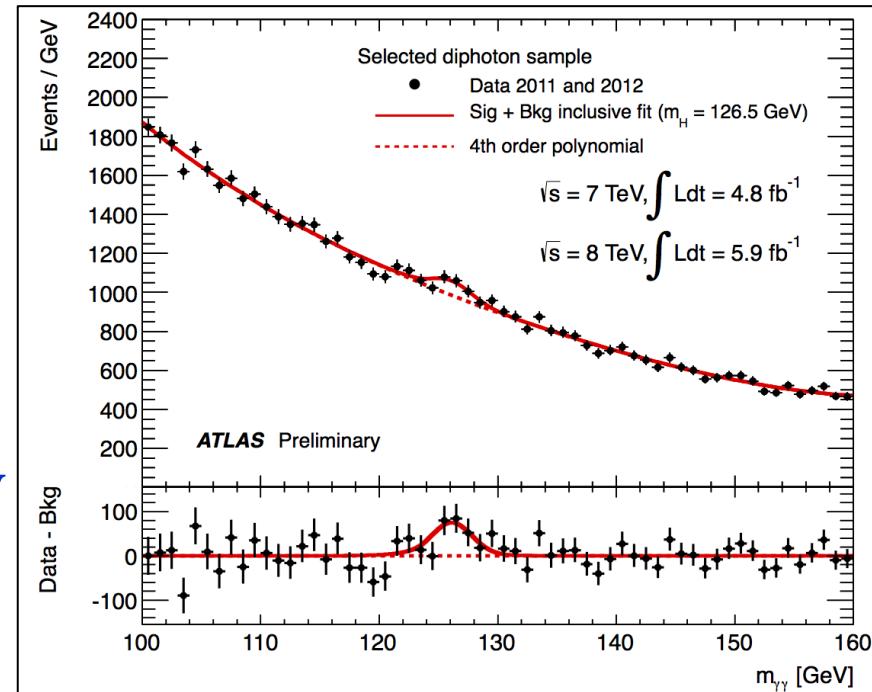
H $\gamma\gamma$ statistical analysis

- Events divided into 9 + 1 categories (*increases statistical power*)
 - 9: converted/ NC; barrel/forward, p_{Tt} diphoton)
 - +1: 2-jets category => *VBF process*
 - 2 jets $p_T > 30/25 \text{ GeV}$, $\Delta\eta_{jj} > 2.8$, $M_{jj} > 400 \text{ GeV}$, $|\Delta\phi|(\gamma\gamma\text{-jj}) > 2.6$



- Fit m($\gamma\gamma$) spectrum in each category with smooth background (parametrization optimized in MC) + signal lineshape

max deviation from background: 126.5 GeV
 ~ 360 evts excess



inclusive distribution, signal fitted at 126.5 GeV

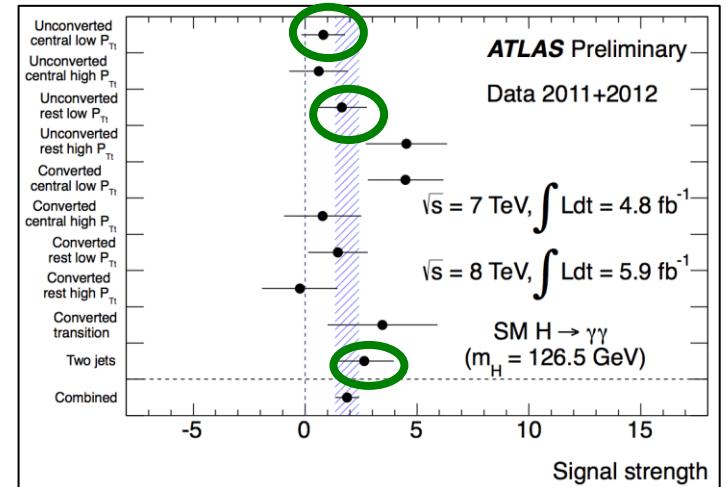
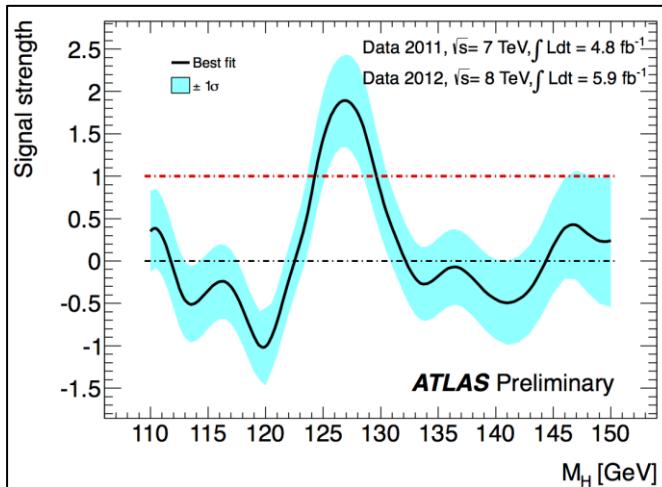
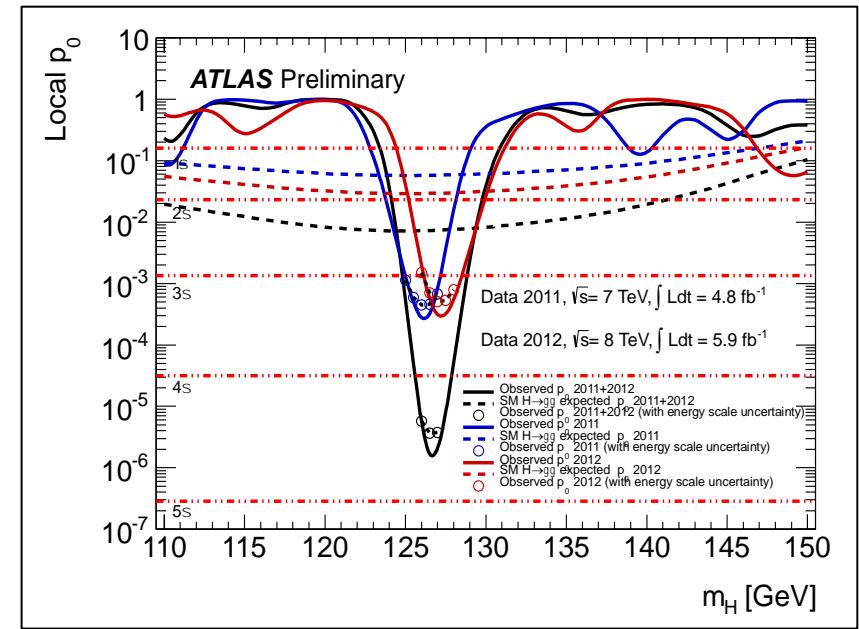
H_{γγ}: results

2011, 7 TeV: 3.5σ at 126 GeV (exp: 1.4)

2012, 8 TeV: 3.4σ at 127 GeV (exp: 1.9)

Combined: 4.5σ at 126.5 GeV (exp: 2.4)

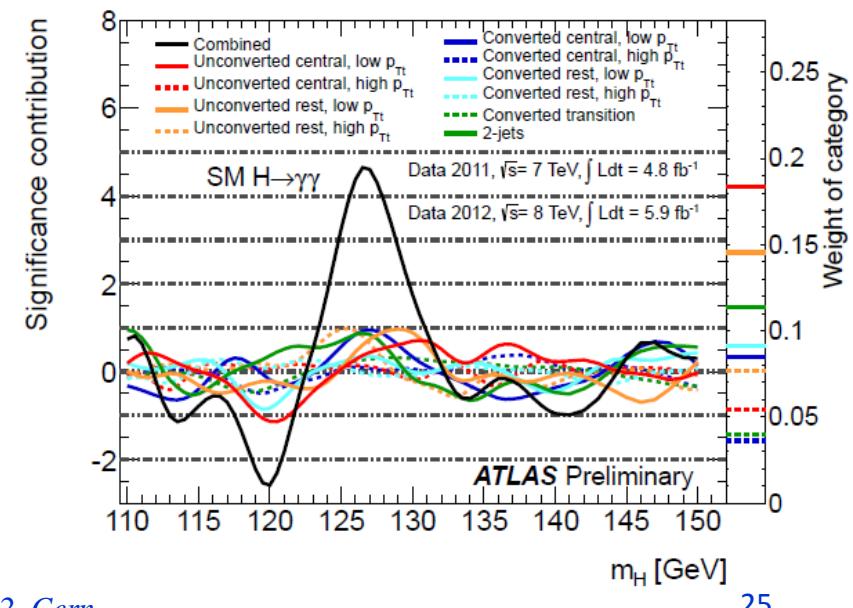
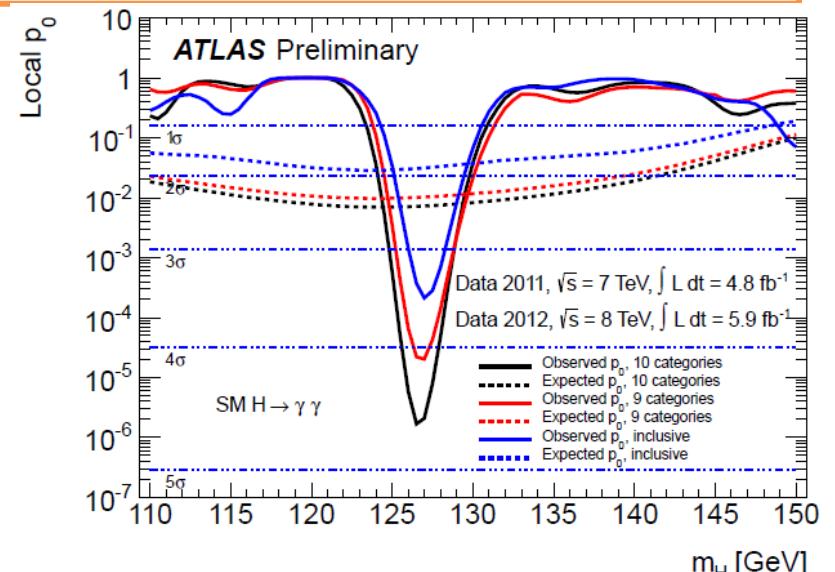
Peak signal strength: $\mu = 1.9 \pm 0.5$ (x SM)



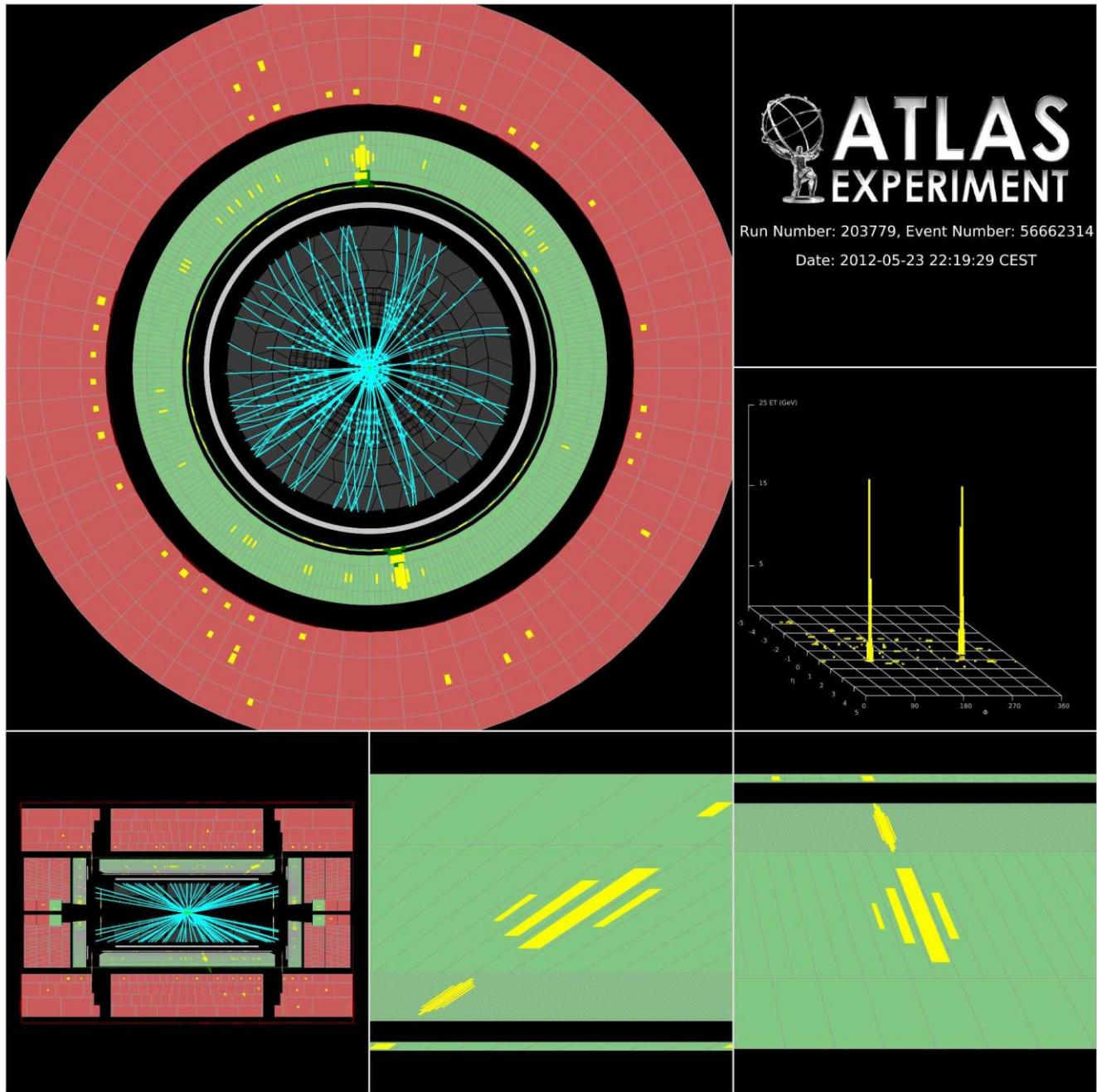
Hgg: cross-checks

- **Comparison**
 - full analysis (10 categories)
 - without 2-jets category (9 categories)
 - inclusive (1 category)
- **Weighted significance per category**
 - Coloured curves: each category significance x weight in combination

Signal comes from several categories

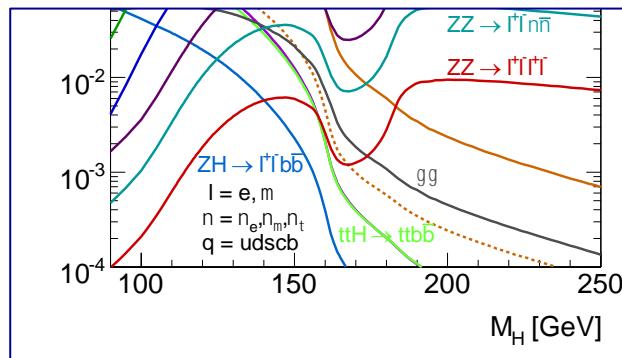


- γ_1
 $E_T = 62.2 \text{ GeV}$
 $\eta = 0.39$
- γ_2
 $E_T = 55.5 \text{ GeV}$
 $\eta = 1.18$
- $m(\gamma\gamma) = 126.9 \text{ GeV}$

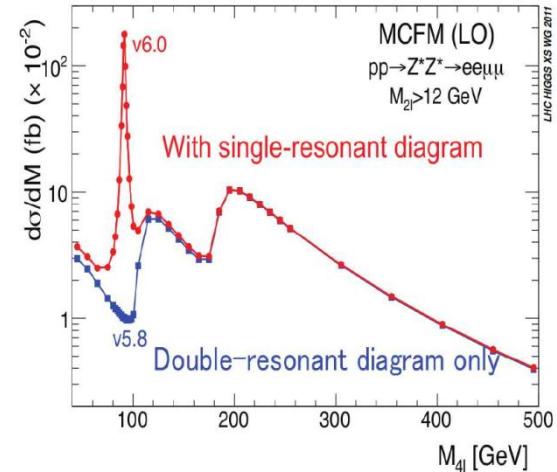
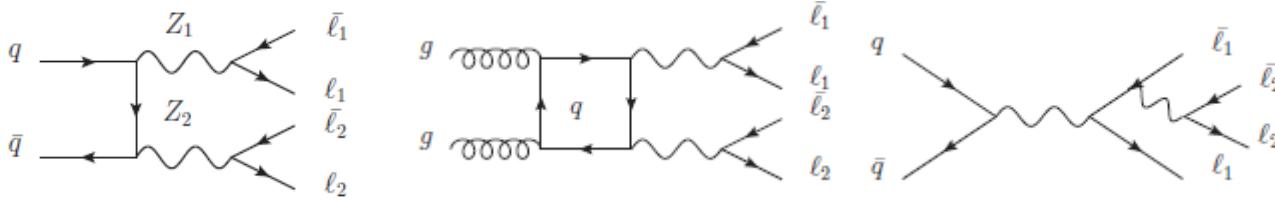


Higgs \rightarrow 4 leptons (e, μ) (Nikolopoulos)

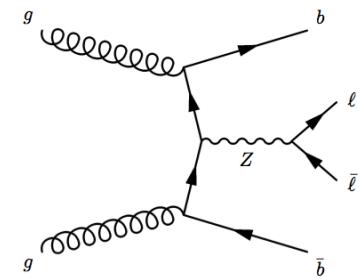
- 2011 + 2012 data
- Signal : $H \rightarrow Z Z^*$ [$m(H) < 2 m(Z)$]
 $Z \rightarrow e^+e^- (\mu^+\mu^-)$: BR = 3%



- Backgrounds
 - Irreducible: continuum 4 leptons

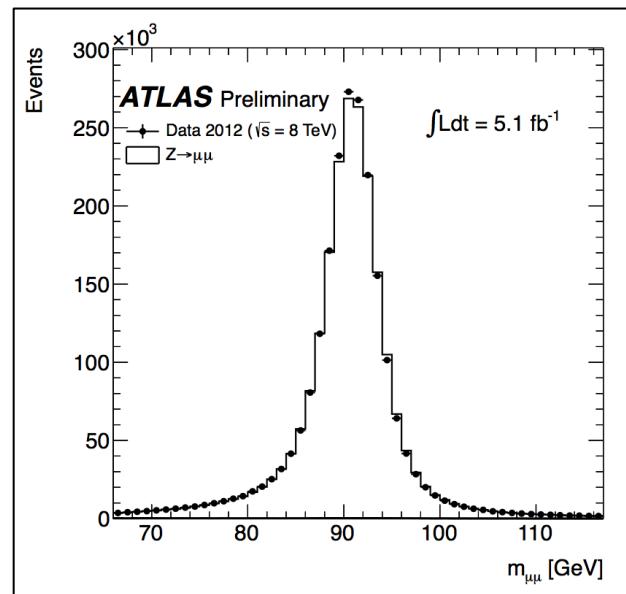
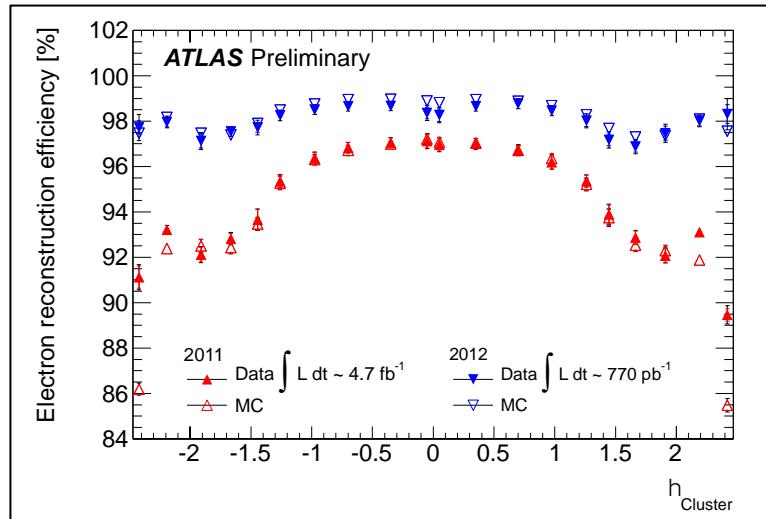


- Reducible (mostly at low mass)
 - $Z b\bar{b} +$ semileptonic decays \Rightarrow lepton isolation, veto b-tag
 - Z jets + « fake leptons » \Rightarrow lepton ID, isolation
 - $t\bar{t} \Rightarrow$ one lepton pair close to $m(Z)$



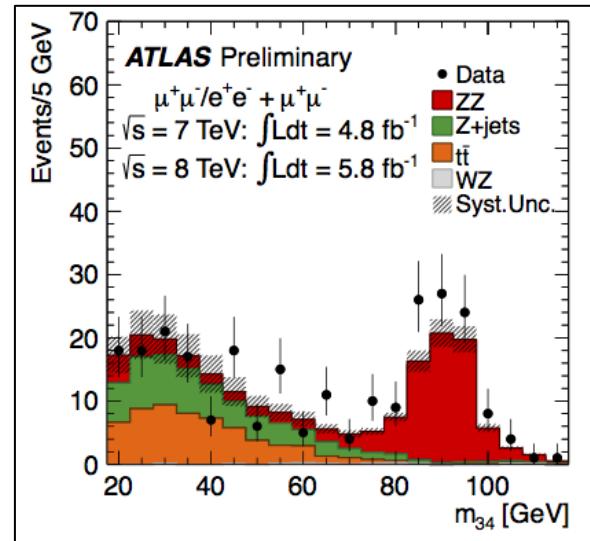
H4I: analysis

- **Optimize signal efficiency**
 - Kinematical cuts: 4 leptons, $p_T > (20, 15, 10, 7\text{-}6)$; $50 < m_{12} < 106$; $m_{34} > 17.5\text{-}50$ GeV
 - Lepton reconstruction
 - At low p_T
 - Over maximal η -range
 - Against pileup (isolation...)
- Momentum resolution
 - On each lepton (check on Z peak)
 - Z mass constraint
 - ZZ*



H4I : backgrounds

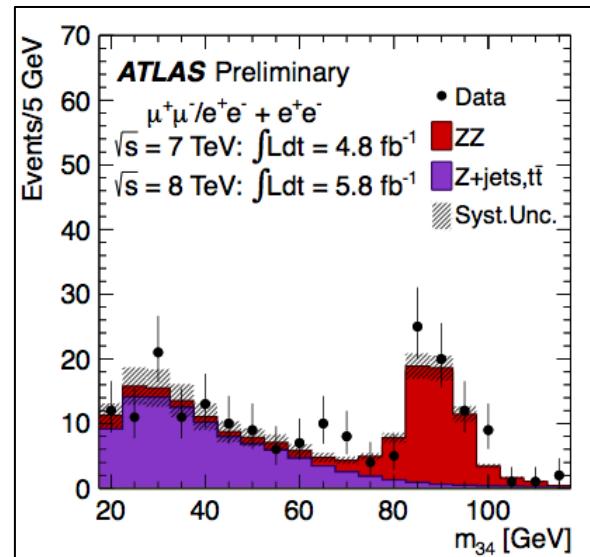
- Control backgrounds
 - 4 lepton continuum (theory + MC)
 - Reducible (Z+jets, Zbb, tt)
 - Use control regions



leading pair : normal selection

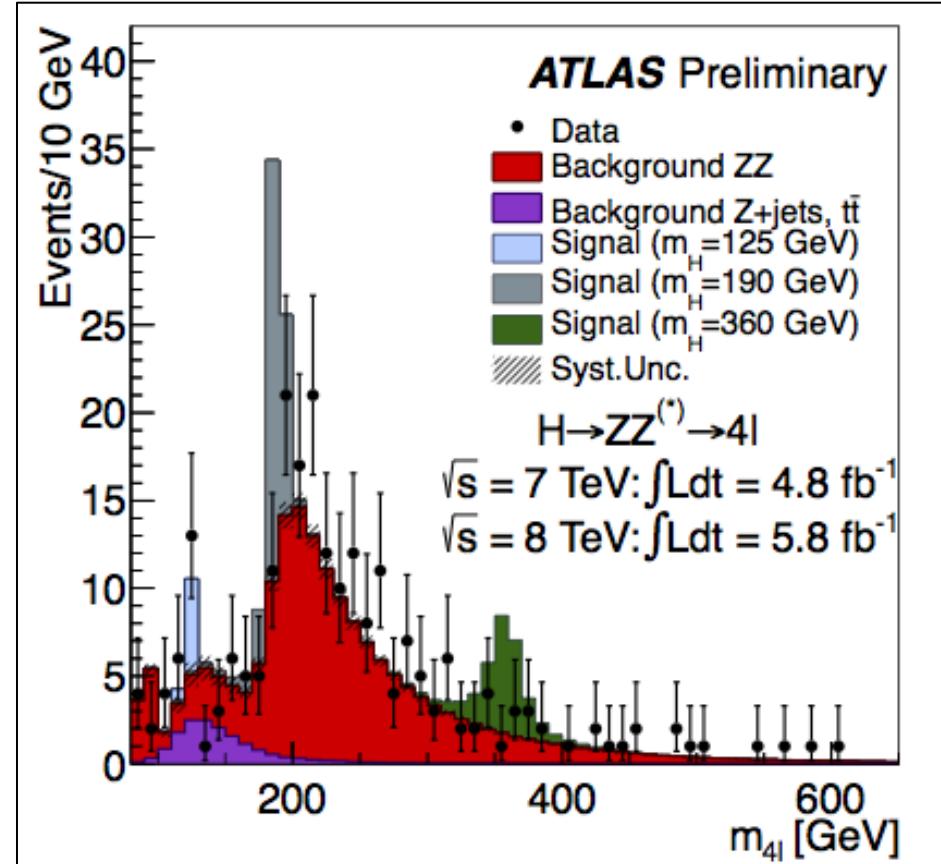
subleading : no isolation and/or impact parameter cut

- Check good data/MC agreement
- Normalize MC to data,
- Use MC to transfer to signal region.



H4l: full spectrum

- 4 lepton mass distribution for 7 TeV and 8 TeV data
- High mass ($m(4l) > 160$ GeV) dominated by ZZ continuum:
1.3 x expected from ZZ theory
(agreement with ZZ cross-section measurement and same tendency with other diboson cross-sections)

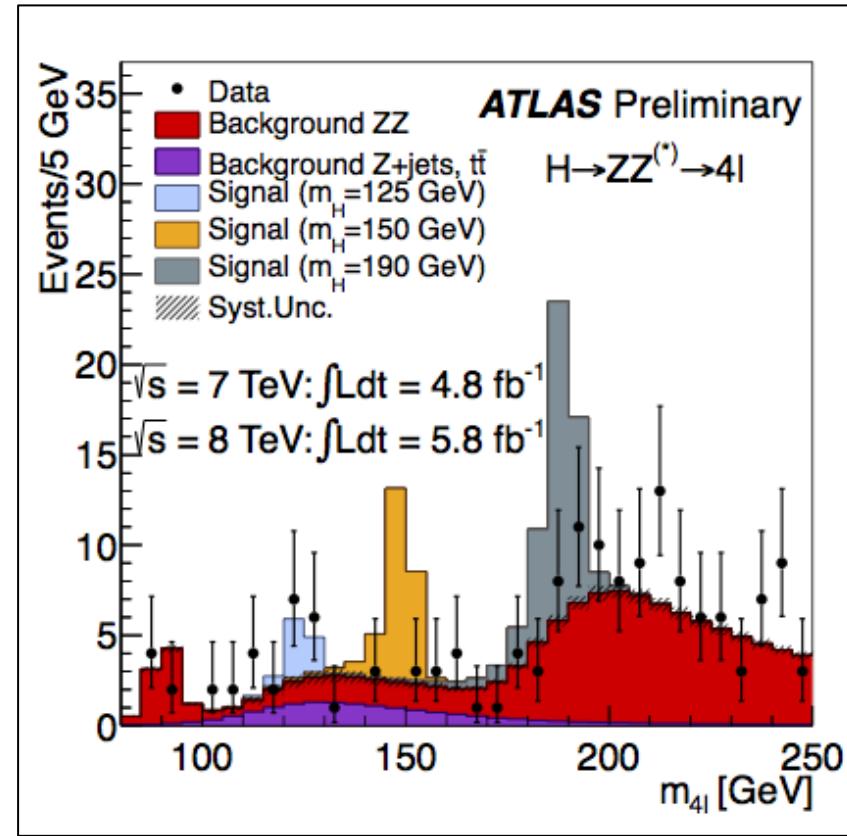


Normalizing continuum to data (high mass) or not: tiny effect on low mass region significance.

H4I : low-mass region

- Region 125 ± 5 GeV:

	4 μ	2e 2μ	4e
Data	6	5	2
Higgs	$2.1 \pm .3$	$2.3 \pm .3$	$0.9 \pm .1$
Bkd	$1.3 \pm .1$	$2.2 \pm .2$	$1.6 \pm .2$
reducible/total	5%	45%	55%



H4l event display

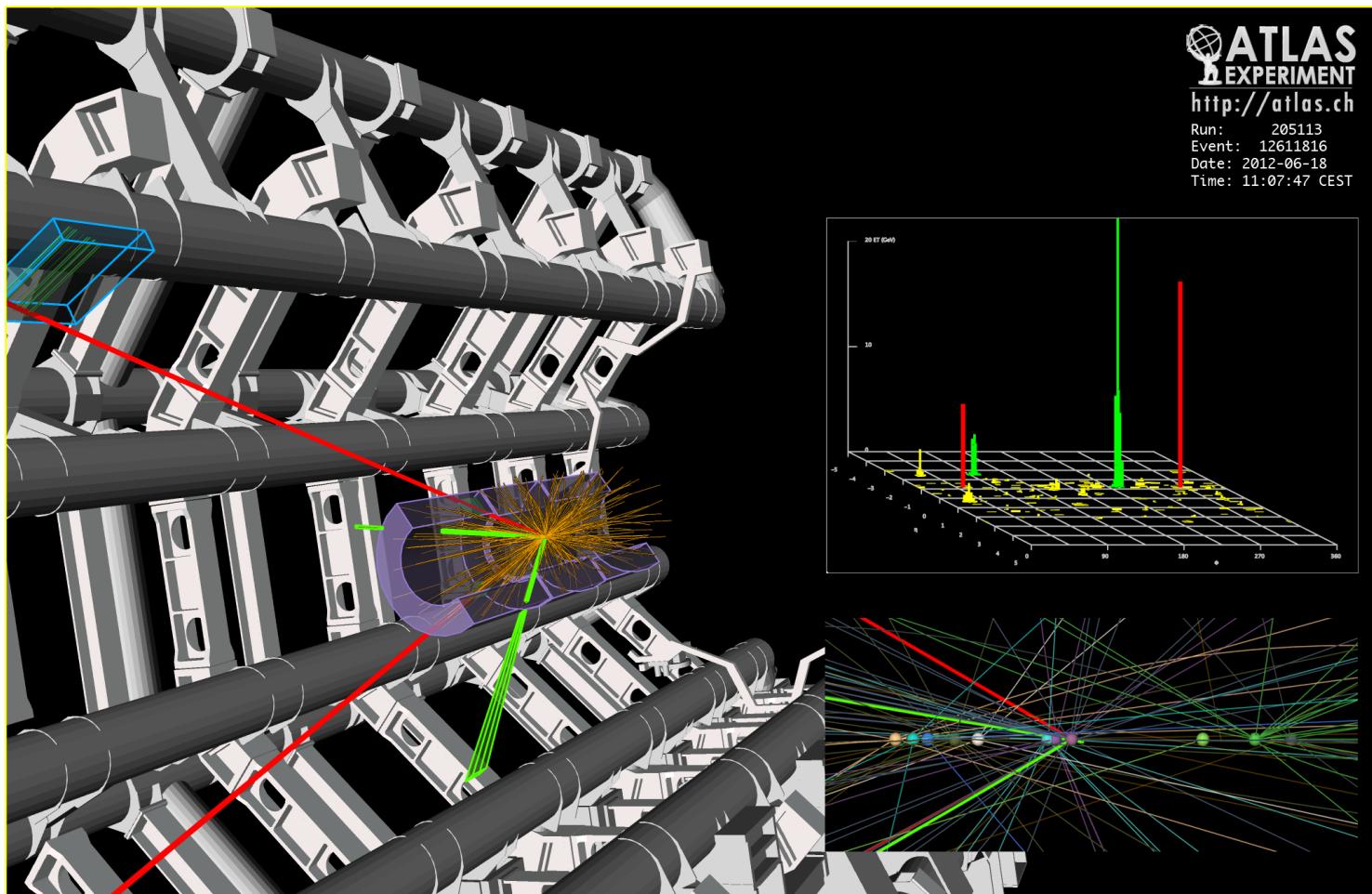
2e 2 μ candidate

$$m(ee) = 87.9 \text{ GeV}$$

$$m(\mu\mu) = 19.6 \text{ GeV}$$

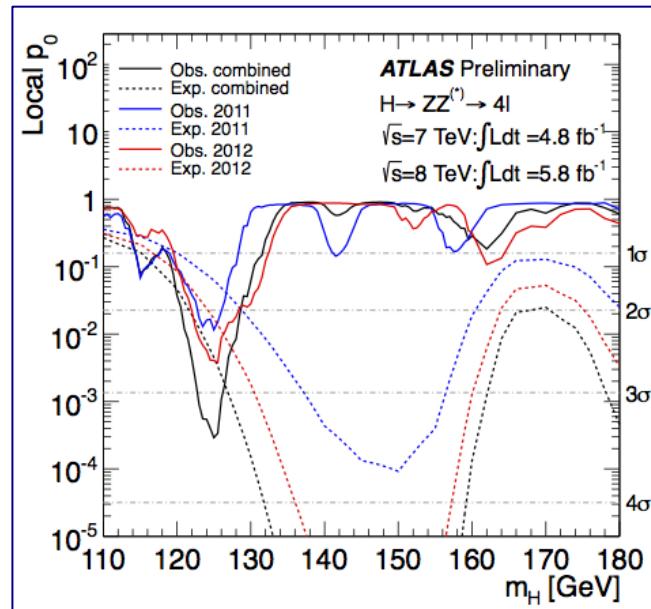
$$M(4l) = 123.9 \text{ GeV}$$

12 vertices



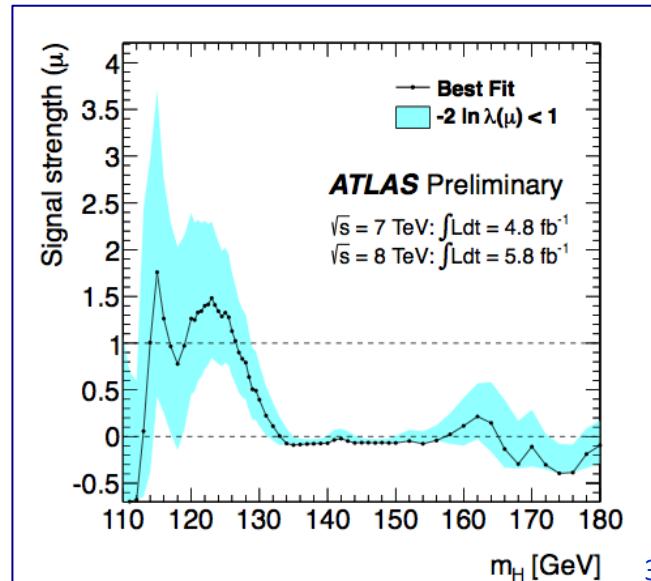
H4I results

- Excess seen around 125 GeV
in 2011 (7 TeV) : 2.3σ (exp: 1.5σ)
and 2012 (8 TeV) : 2.7σ (exp: 2.1σ)
Total : 3.4σ (exp: 2.6σ)



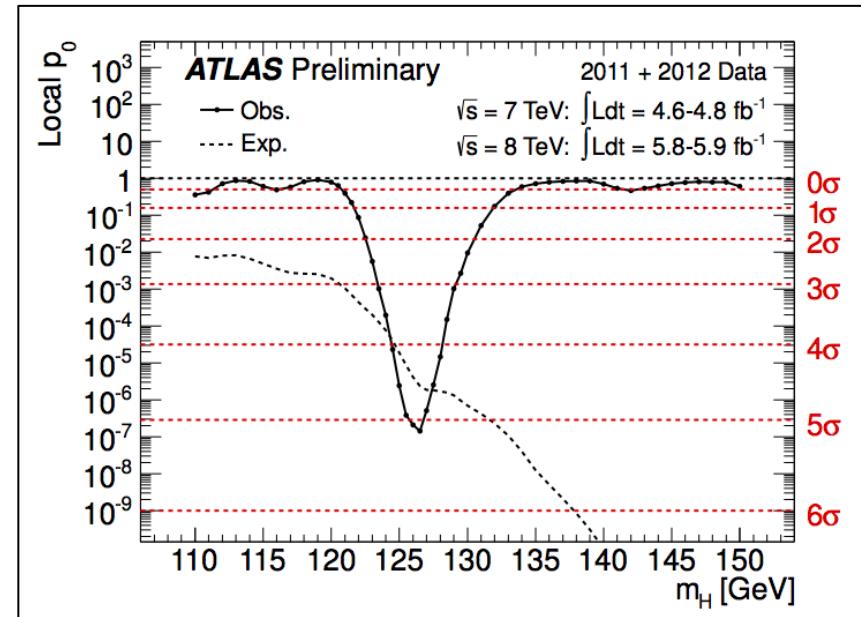
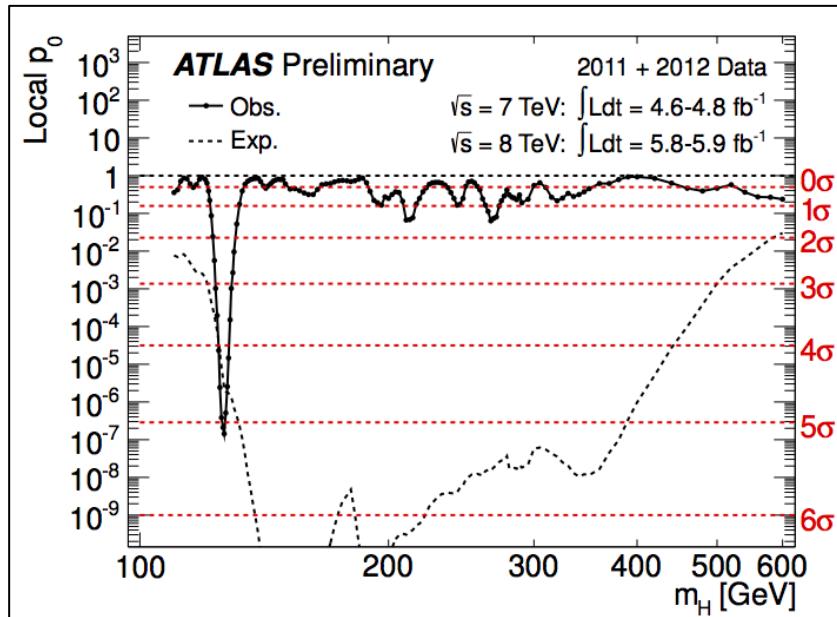
- Best fit signal strength value
at 125 GeV: $\mu = 1.3 \pm 0.6$

*Note: peak at 114 is not significant:
 μ large but ~no signal expected...*



Combination (Hawkings)

- Combine $H\gamma\gamma + H4l$ (2011+2012) + all other channels (2011)



- Consistent with background-only everywhere
- Except in one (unexcluded) region
 - Maximum excess around **126.5 GeV**
 - Local significance **5.0 σ** (probability of background fluctuation $p_0 = 3 \cdot 10^{-7}$)
 - Expected from SM Higgs: 4.6 σ

Combined: results

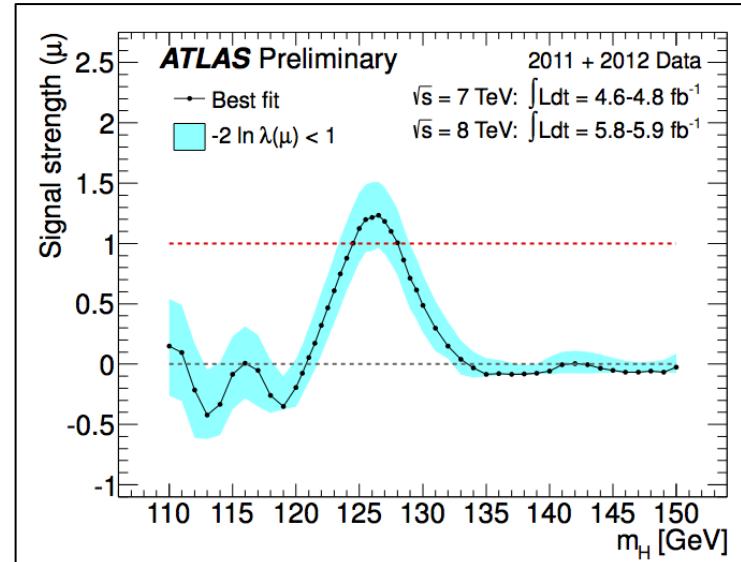
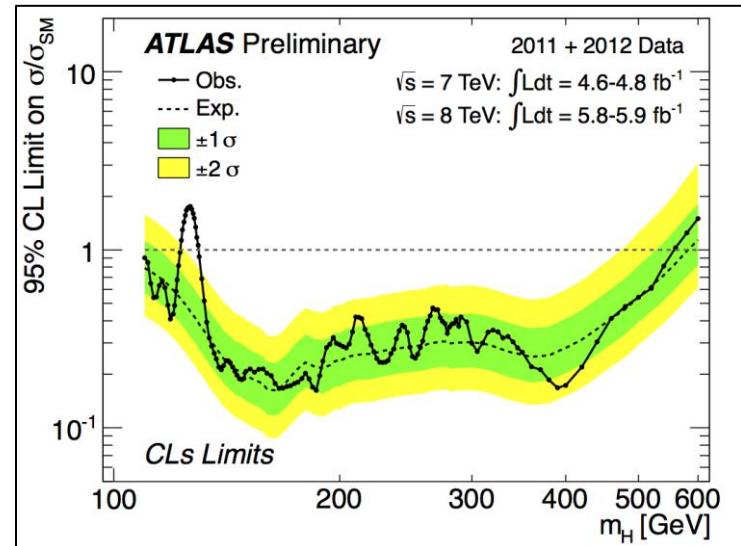
- SM Higgs excluded

95%CL : 110-558 GeV (except 122.6-129.7)

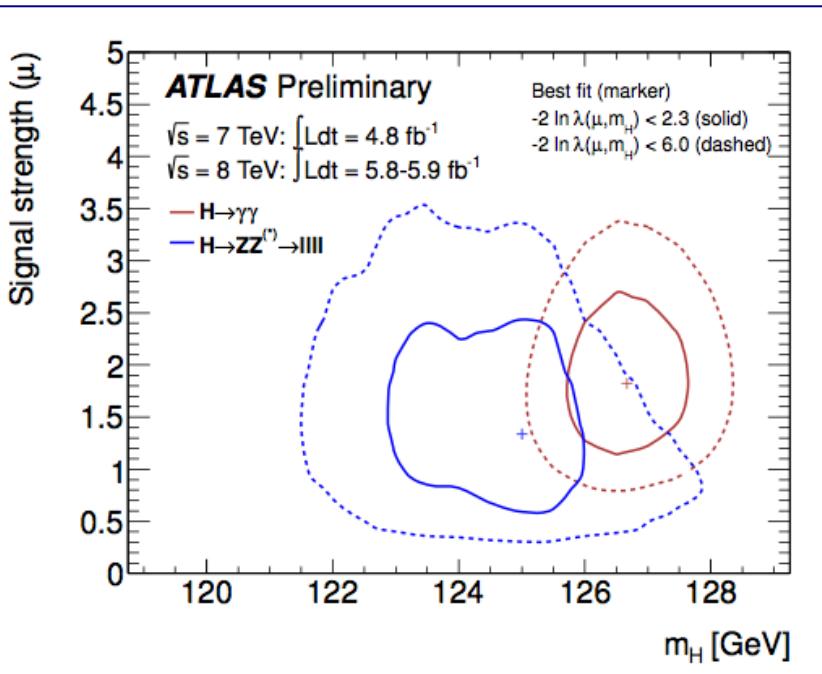
99% CL : 111.7-523 GeV (except 121.8-130.7)

- Best-fit signal strength at 126.5 GeV

$$\mu = 1.2 \pm 0.3$$

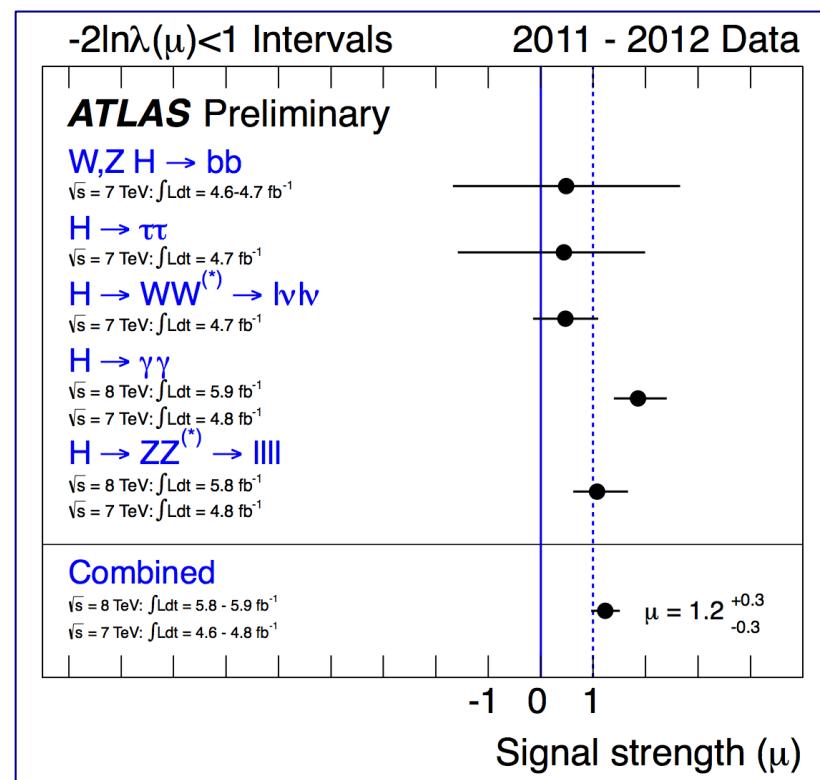


Global picture for SM Higgs



- **H $\gamma\gamma$ and H4l well consistent**

**H $\gamma\gamma$ and H4l : 2011 + 2012
Others : 2011 only**



Conclusions

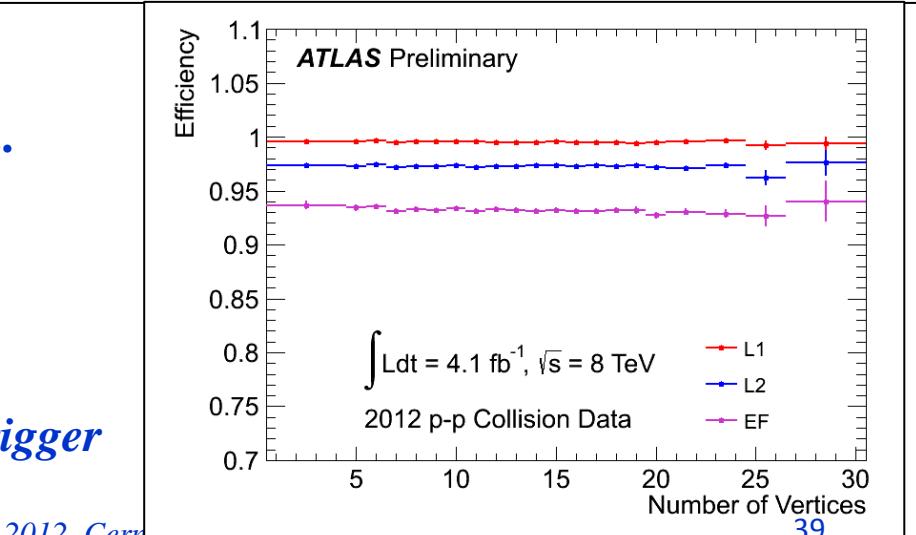
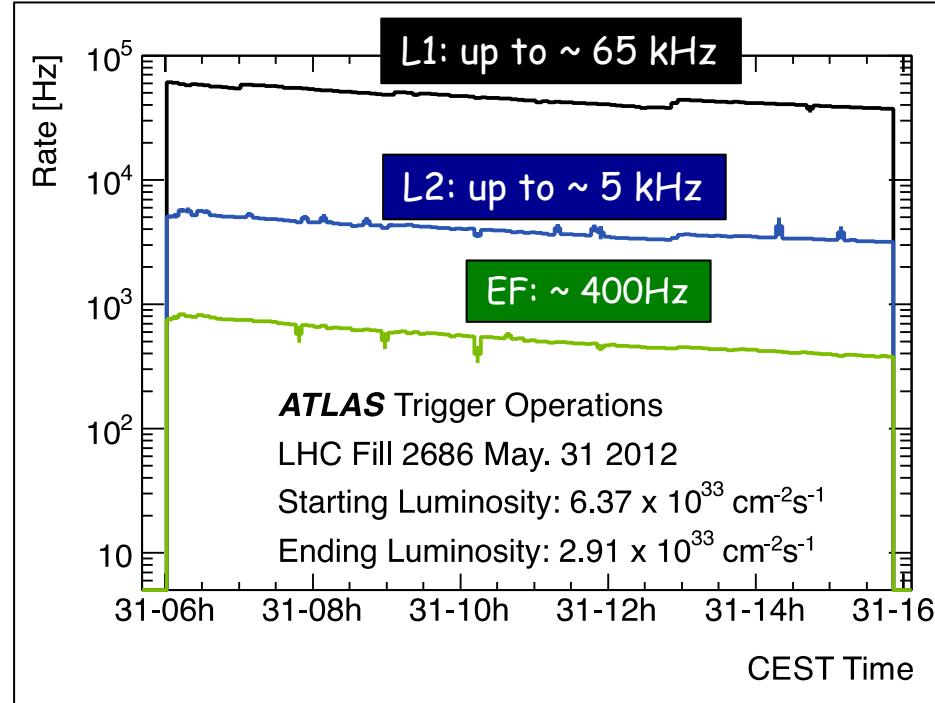
- Excellent operation of the LHC in 2011 and 2012
- Reliable, high-performance Atlas detectors
- Large number of new results presented at ICHEP
 - Among which the Higgs ‘observation’ of course
 - *All results also available on <https://twiki.cern.ch/twiki/bin/view/AtlasPublic>*
- Near and short-term future:
 - Combined paper end of July (including HWW 2011 + 2012)
 - Other Higgs modes : end of summer
 - p-p run extended to Christmas shut-down => 20 fb^{-1} ?
- 2014 and more: 14 TeV, luminosity increase...
 - More on the Higgs (standard? etc.)
 - New territory for searches
 - *Atlas upgrade programme*

Additional slides

Trigger

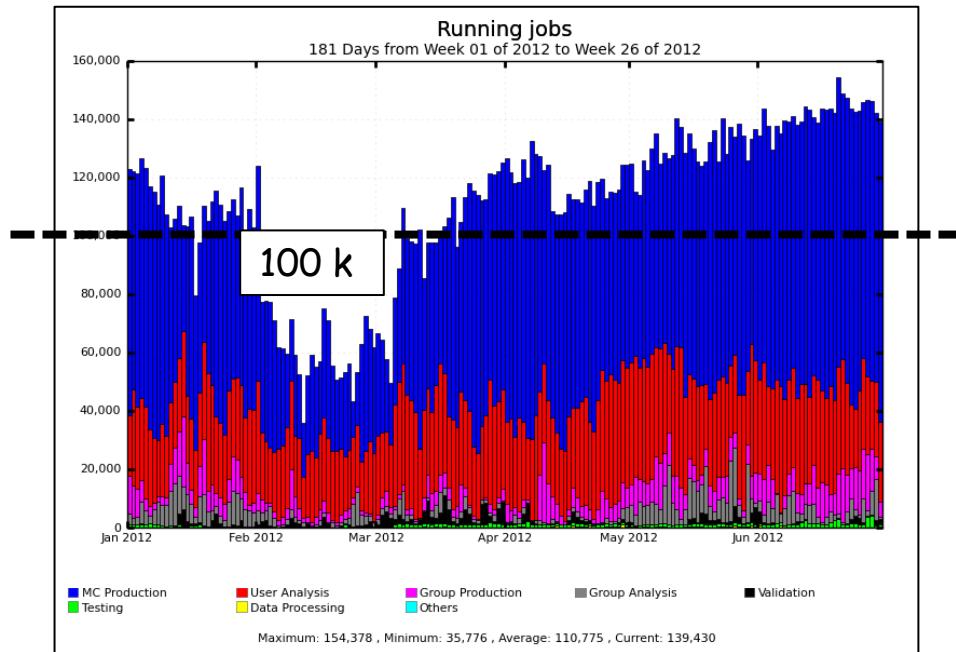
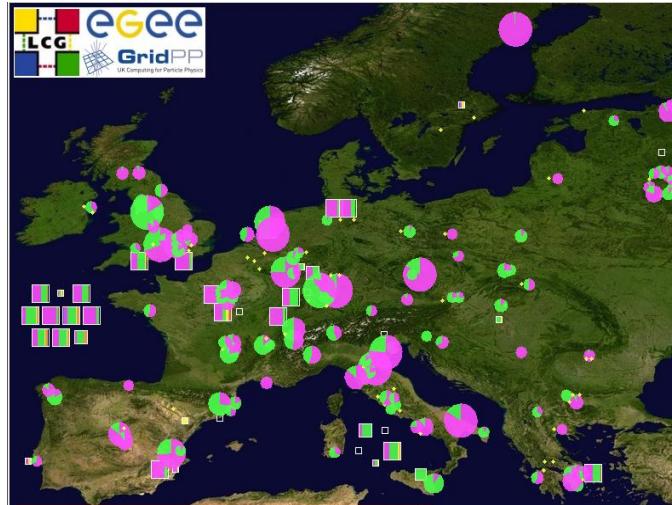
- **Atlas trigger made in 3 levels**
 - L1 : fast (dedicated hardware)
calorimeters and muon spectrometer
 - L2 : dedicated software
 - L3: event filter
- **Each level uses phys object primitives**
EM cluster, muon hits, $E_{T\text{miss}}$...
- **Menu contains ~500 lines**
 - Single e, single μ , 2 e, 2 μ , $E_{t\text{miss}}$, etc., etc.
- **Pile-up robust algorithms**

inclusive electron trigger



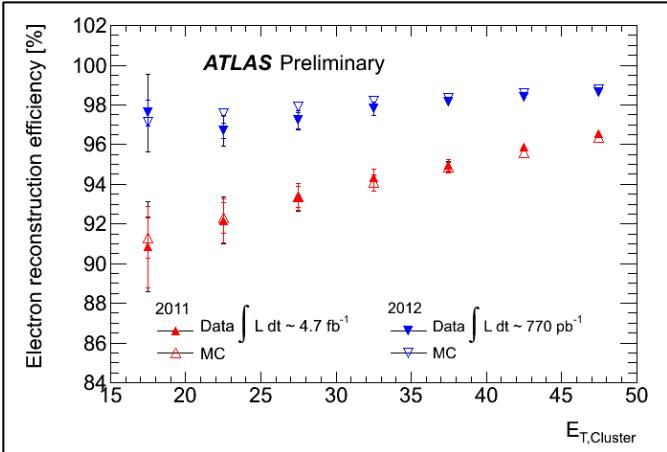
Data processing

- Output of Event Filter:
~400 events/s recorded to disk
- Data processed on the computing-grid (80 sites)
 - Event reconstruction
 - Monte-Carlo production
 - Analysis
- 1500 distinct users on the Grid

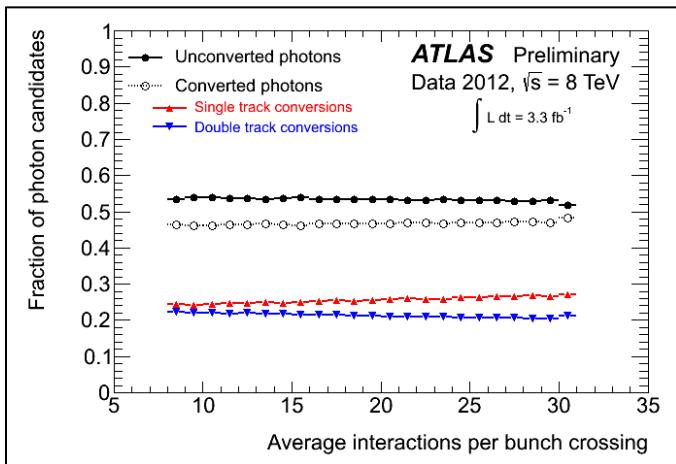
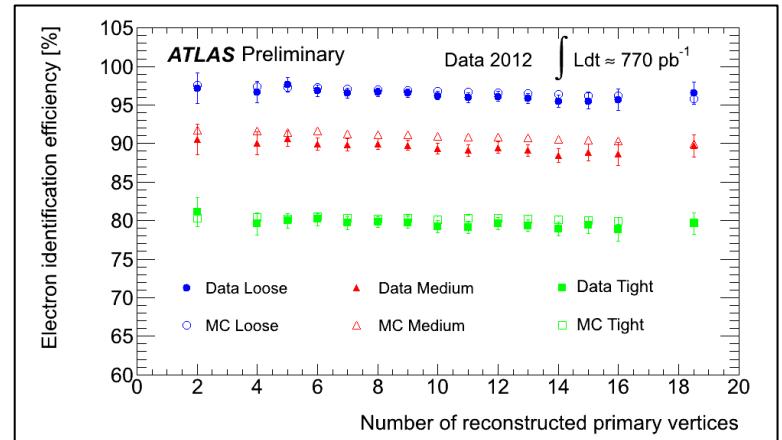


Physics objects optimization: Electrons, photons, muons

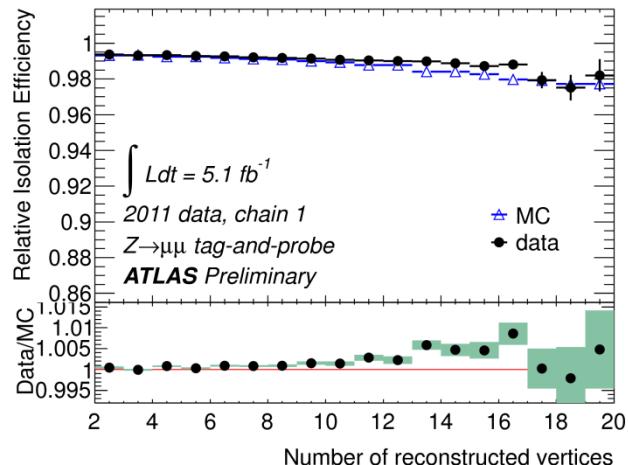
Low p_T electrons



Electron efficiency / pile-up



Photon efficiency / pile-up



Muon isolation / pile-up