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Beyond the Standard Model: Results with the 7 TeV LHC Collision Data

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Higgs Boson Searches with the ATLAS Detector

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Higgs Boson Searches with the ATLAS Detector

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On the behalf of the ATLAS Collaboration

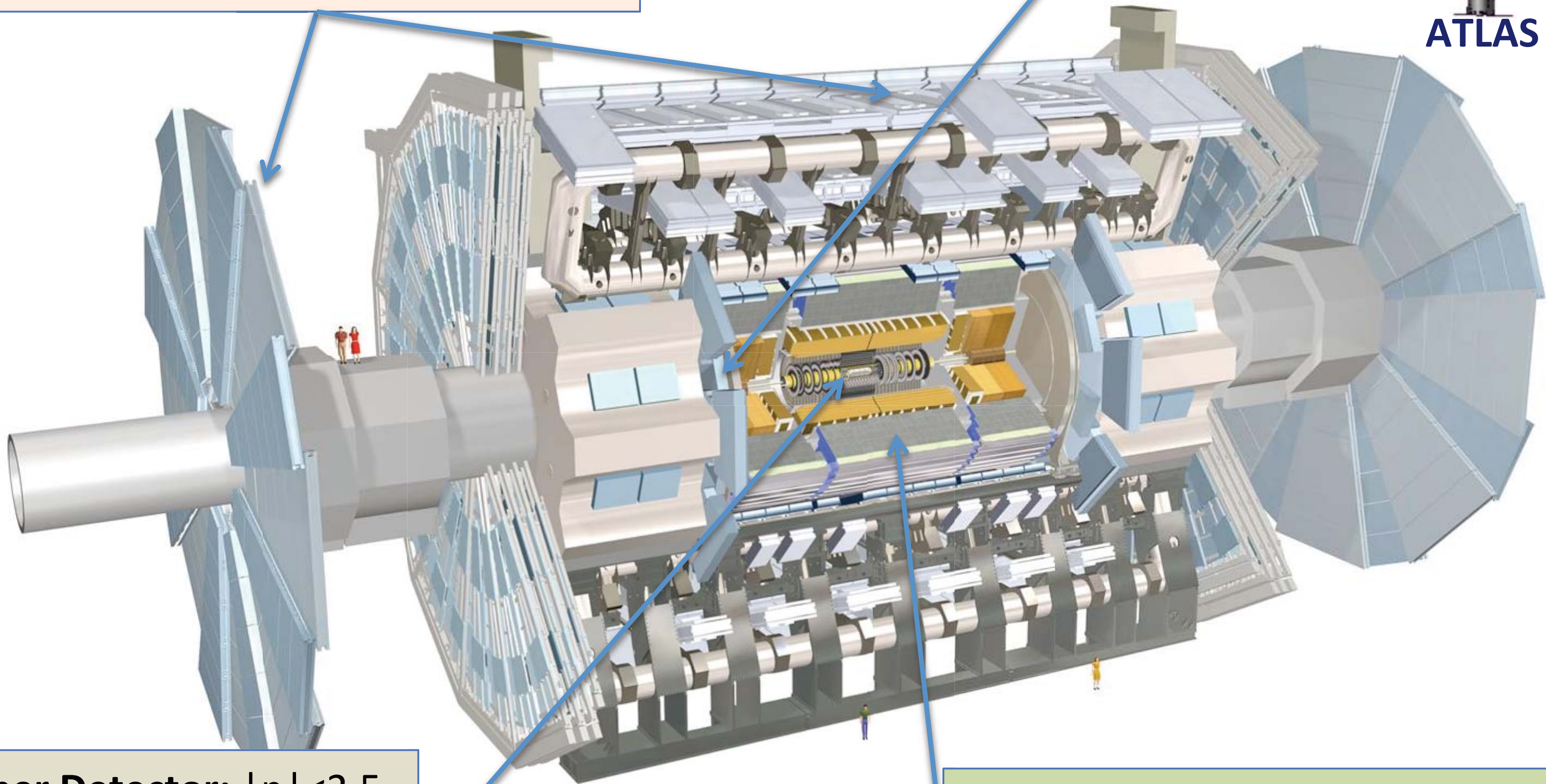
outline

- ATLAS Detector
- SM Higgs production and decay
- SM Higgs searches
  - $H \rightarrow \gamma\gamma$
  - Associated production $H \rightarrow$ bb-bar
  - $H \rightarrow \tau\tau$
  - $H \rightarrow WW^{(*)} \rightarrow l\nu l\nu$
  - $H \rightarrow WW \rightarrow l\nu qq$
  - $H \rightarrow ZZ \rightarrow llqq$
  - $H \rightarrow ZZ \rightarrow ll\nu\nu$
  - $H \rightarrow ZZ^{(*)} \rightarrow llll$
- SM Higgs Combination
- MSSM Higgs searches
  - top $\rightarrow H^{+}b \rightarrow$ csbar b
  - H/A/a $\rightarrow \tau\tau$
- NMSSM H $\rightarrow \mu\mu$

The ATLAS detector

Muon Spectrometer: |η|<2.7
Air-core toroids and gas-based muon chambers σ/p_T = 2% @ 50 GeV to 10% @ 1TeV (ID+MS)

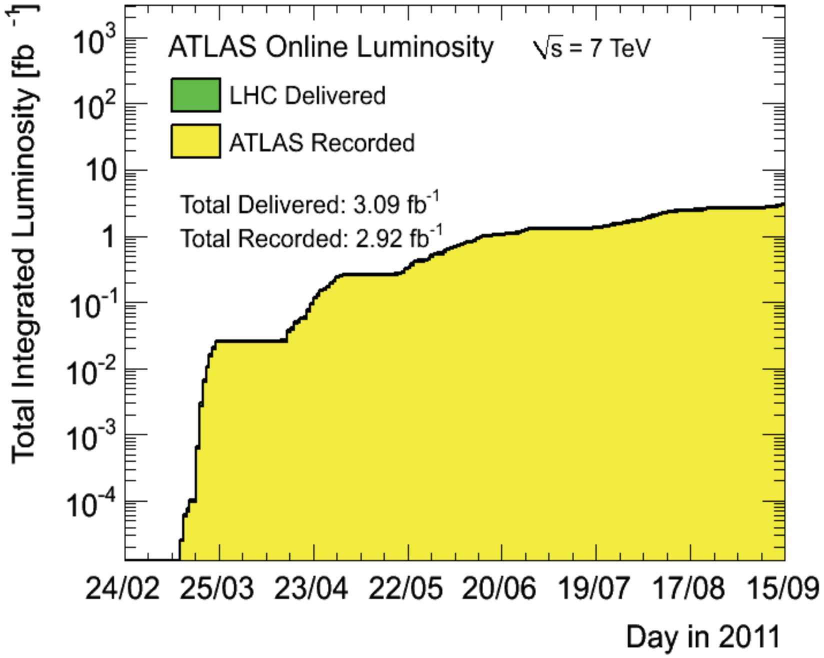
EM Calorimeter: |η|<3.2
Pb-LAr Accordion σ/E=10% √E⊕0.7%



Inner Detector: |η|<2.5, B=2T, Si pixels/strips and Trans. Rad. Det.; σ/pT = 0.05% pT (GeV) ⊕ 1%

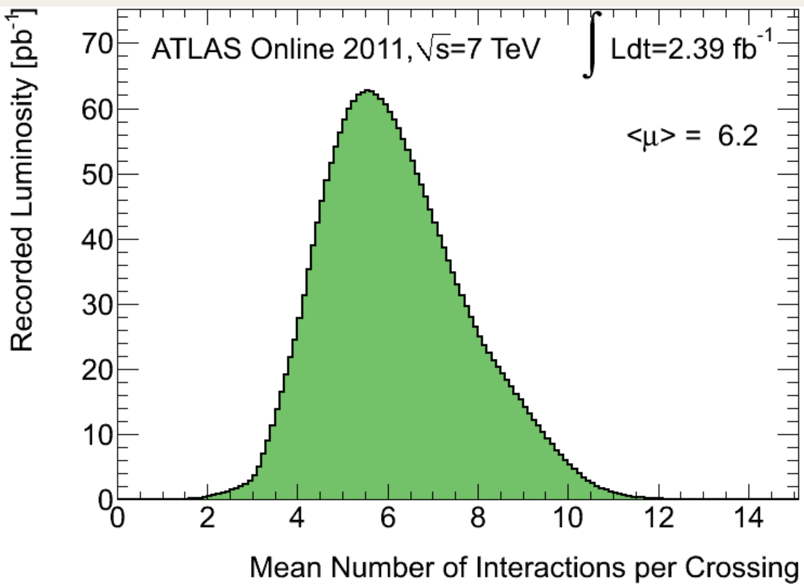
Hadronic calorimeter: |η|<1.7 Fe/scintillator 1.3<|η|<4.9 Cu/W-LAr; σ/Ejet= 50%/√E ⊕ 3%

ATLAS Data Taking in 2011



Data taking efficiency: ~ 95%

Relative fraction of good quality data delivery by the various ATLAS subsystems: between 90 and 100%



Luminosity-weighted distribution of the mean number of interactions per crossing for 2011.

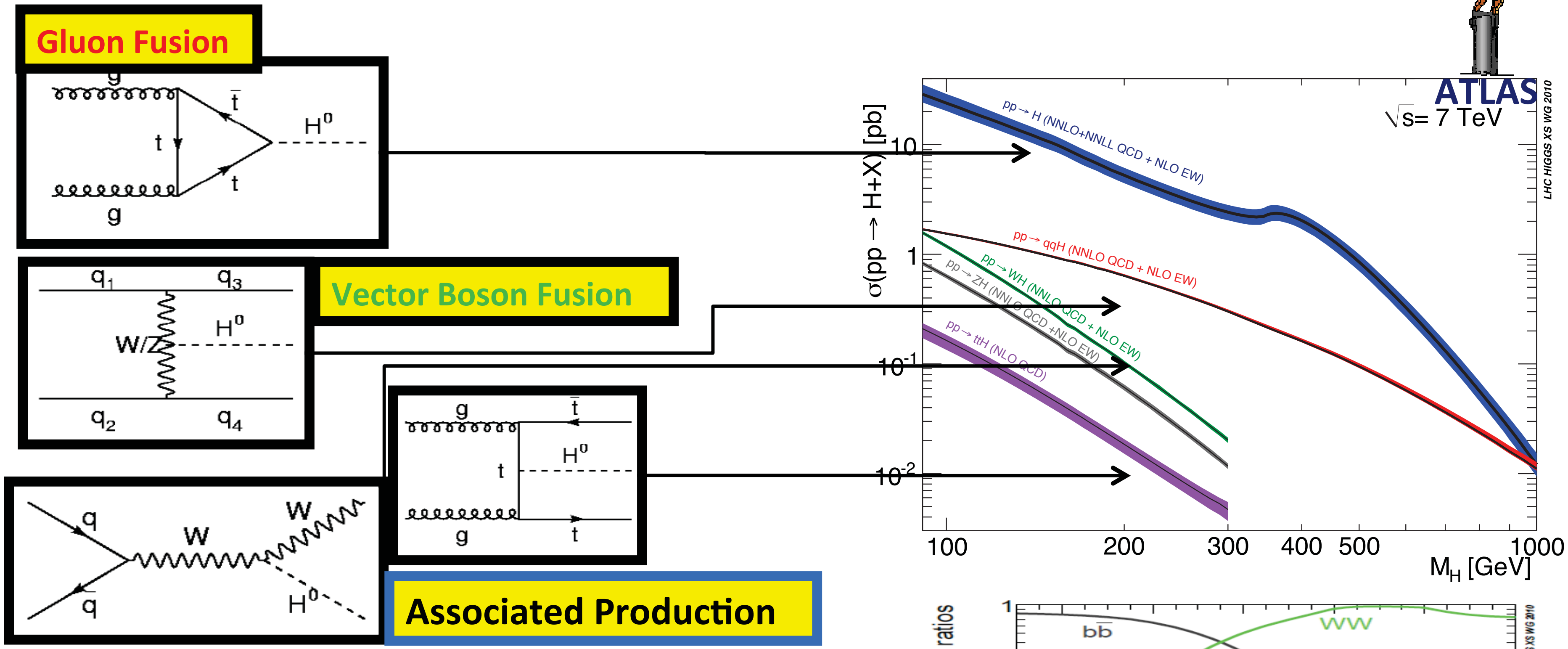
Pile-up challenge:

- 50 ns bunch trains for ~all 2011 data

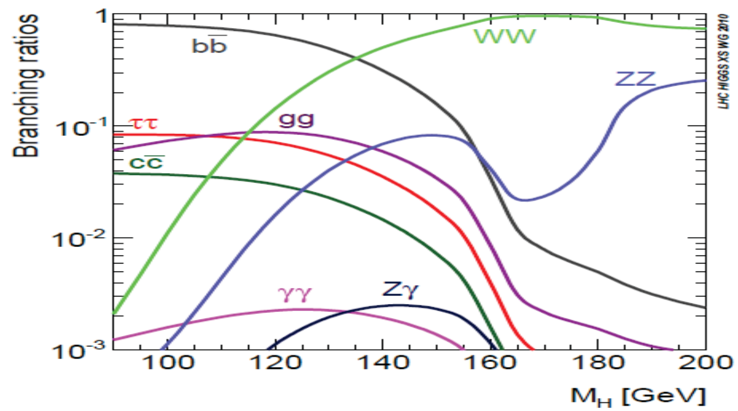
➔ **Substantial in- and out-of-time pileup: μ ≈ 6**

- Much progress understanding impact on performance, with data & simulation
- Continuing detailed performance studies in presence of high pile-up

SM Higgs production at the LHC



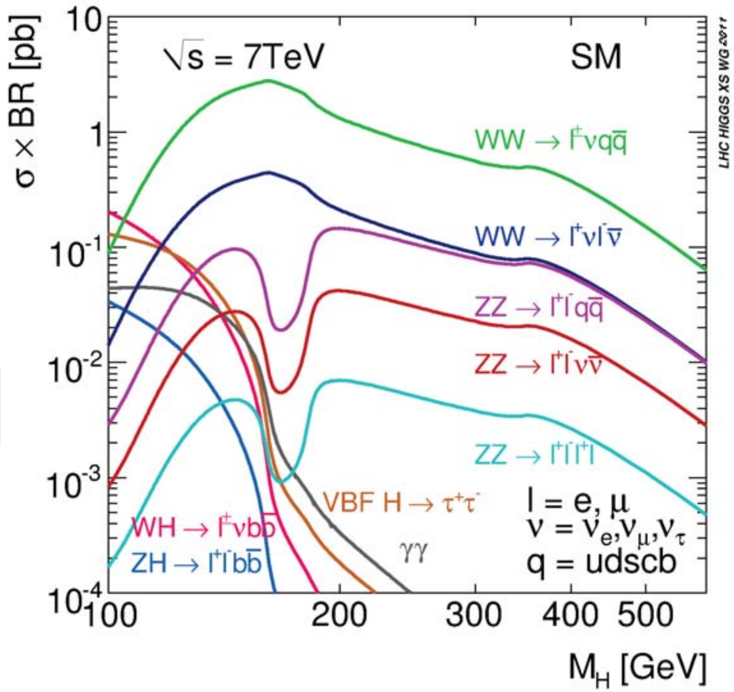
- Gluon fusion is the dominant mechanism for Higgs production at present hadron colliders
  - At LHC this is x10 higher than at Tevatron!
- Associated production is also important: qqH, VH, ttH



Higgs cross-sections

ATLAS

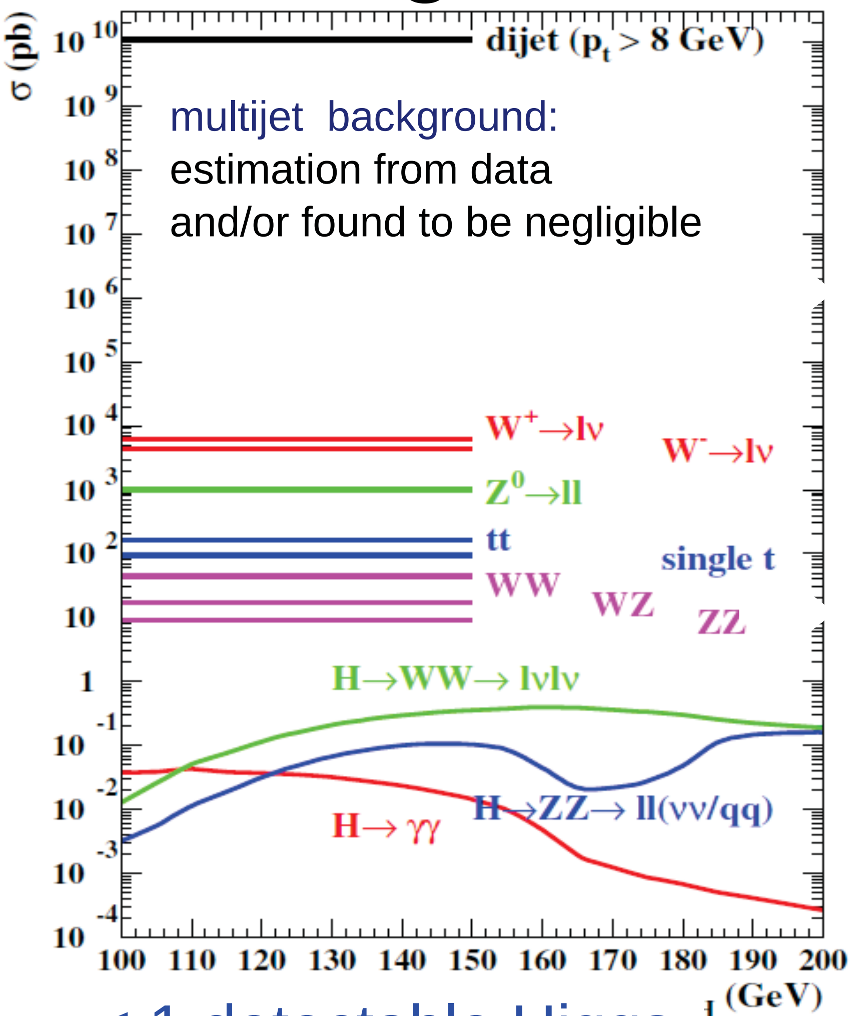
- **H→γγ**: rare channel, but the best for low mass — *L=1.1 fb^{-1}*
- **H→WW$^{(*)}$**:
  - →lvlv: very important in the intermediate mass range — *L=1.7 fb^{-1}*
  - → lvqq: highest rate, important at high mass — *L=1.0 fb^{-1}*
- **H→ZZ$^{(*)}$**:
  - → 4l: golden channel — *L ~ 2.2 fb^{-1}*
  - → llvv: good for high mass — *L=1.0 fb^{-1}*
  - → llbb: also high mass — *L=1.0 fb^{-1}*
- **H→ττ**: good signal/background, important at low mass, rare — *L=1.1 fb^{-1}*
- Associated prod. **H→ bb** — *L=1.0 fb^{-1}*
  - ttH, WH, ZH
  - It is useful for the discovery
  - It is very important for Higgs property studies if SM Higgs is discovered



Events expected to be produced with L=1 fb^{-1}

m_H, GeV	WW→lvlv	ZZ→4l	γγ
120	127	1.5	43
150	390	4.6	16
300	89	3.8	0.04

Signal-to-Background Ratio

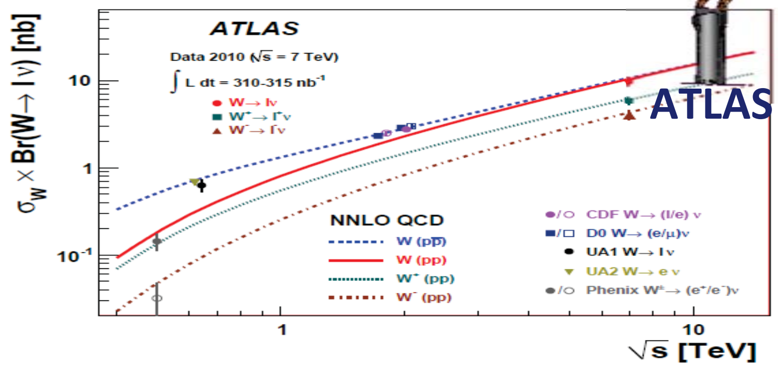


multijet background:
estimation from data
and/or found to be negligible

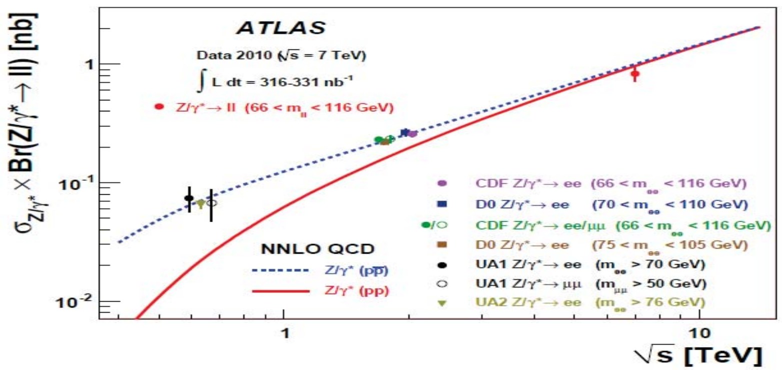
< 1 detectable Higgs boson per 10^{12} collisions

measurements of "EW" backgrounds

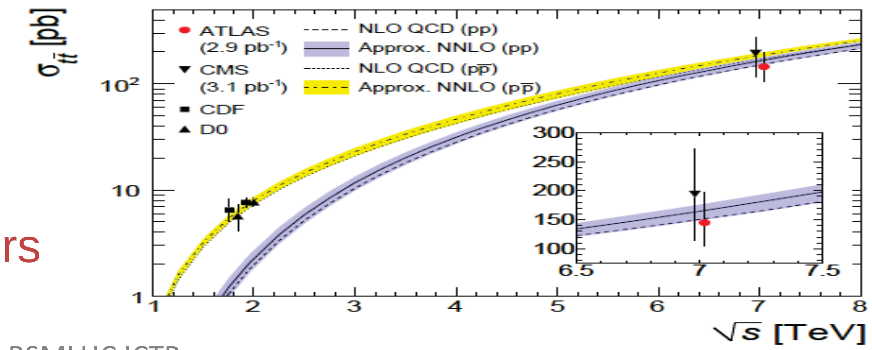
W^+, W^-



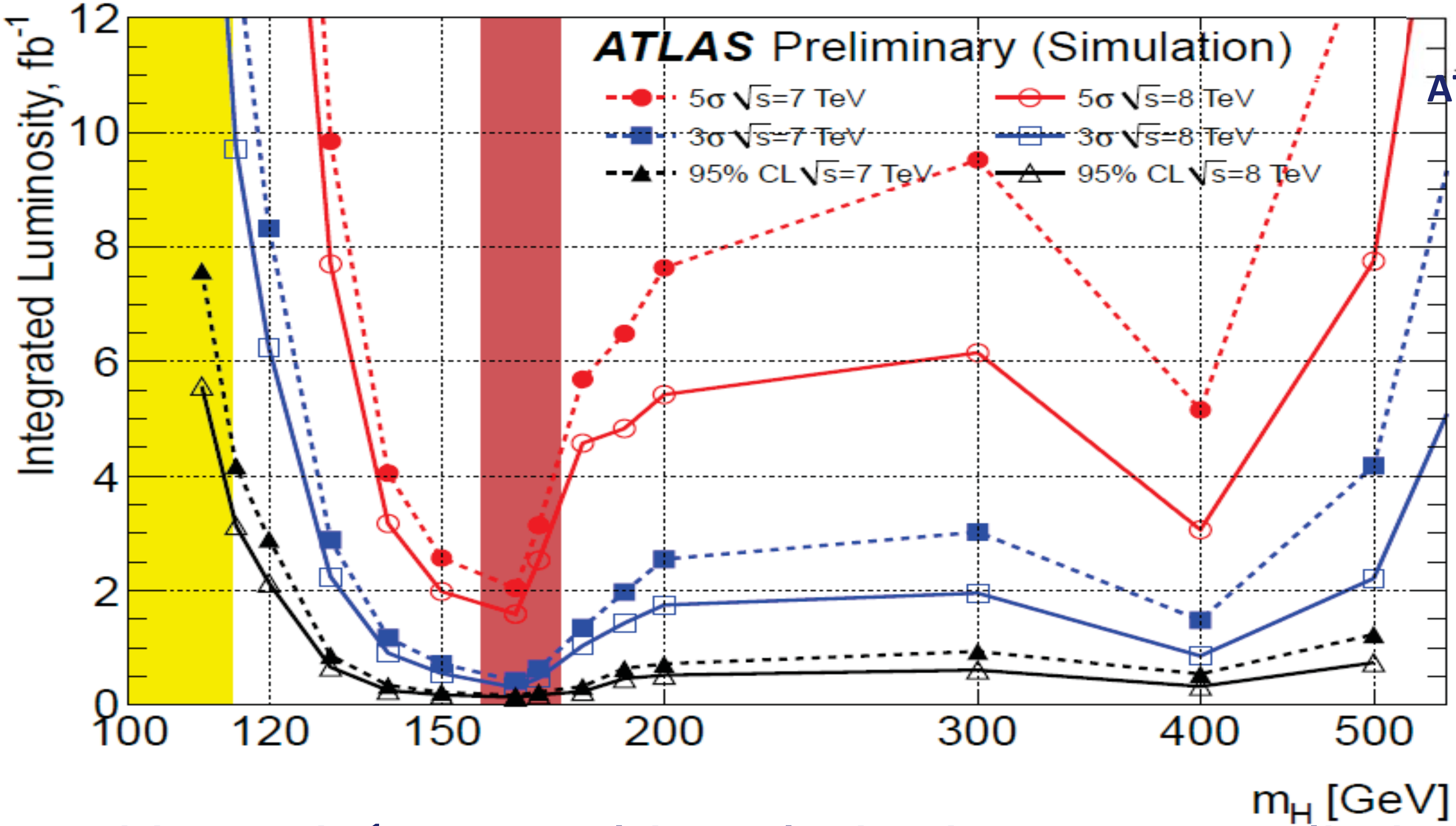
Z/γ*



top pairs



ATLAS Projections for Higgs Searches



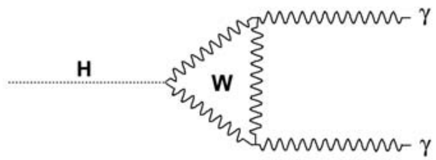
With ~ 4fb^{-1} we could exclude down to LEP limit but hope instead for discovery

H→γγ

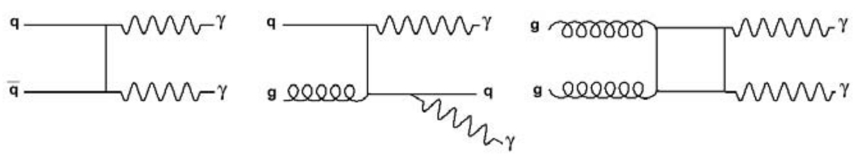
- o small BR (about 0.002)
- o decay due to W and top loops
- o clean 2-γ signature

Higgs to 2γ decay

$\sigma = 0.04$ pb



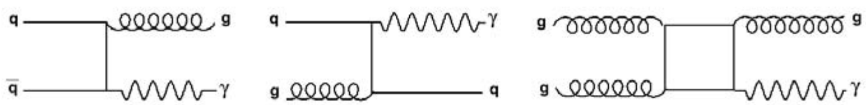
Irreducible background: pp→γγ + X



Born $O(\alpha^2)$ | Bremsstrahlung $O(\alpha_s\alpha^2)$ | Box diagram $O(\alpha^2_s\alpha^2)$

Theoretical uncertainty: ~ **25 %** (NLO: 20%)

qqbar, qg $\sigma \approx 21$ pb
gg $\sigma \approx 8$ pb



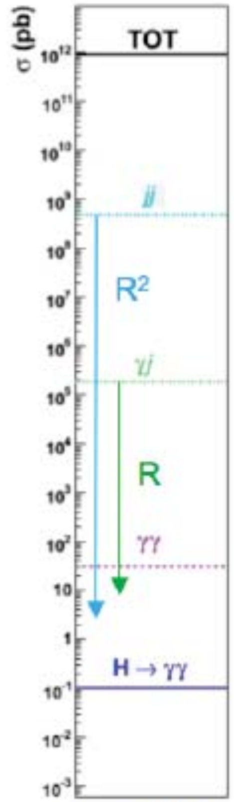
Reducible background: pp→γj , jj+ X

$O(\alpha_s\alpha)$ $O(\alpha_s\alpha)$ $O(\alpha^3_s\alpha)$

γ-jet $\sigma \approx 1.8 \times 10^5$ pb
jet-jet $\sigma \approx 4.8 \times 10^8$ pb

γ-jet need rejection R~O(10 ⁴)
jet-jet need rejection R~O(10 ⁷)

Main background is from leadin



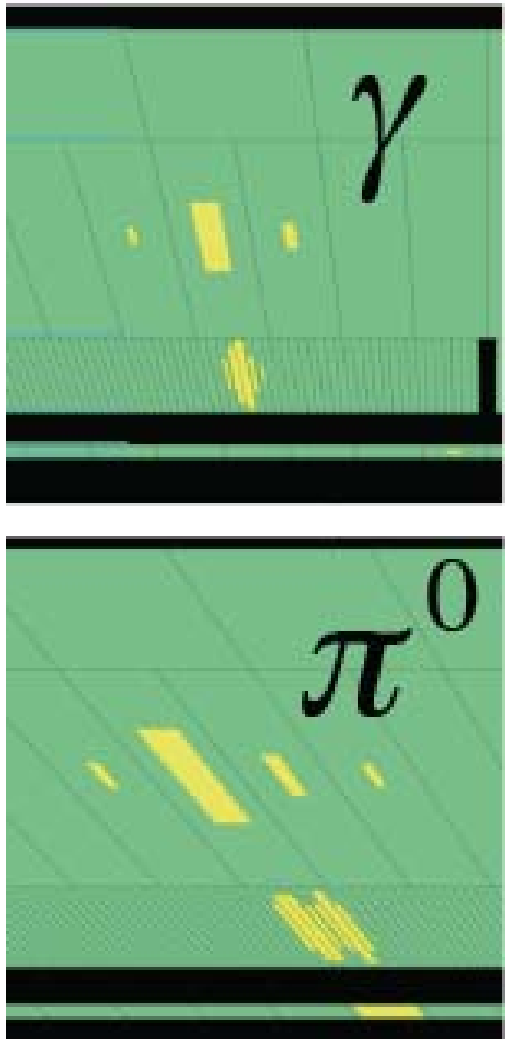
R ~ O(8000)

Theoretical uncertainty: ~ **30%** (dominated by NLO cross-section)

H→γγ – event selection

ATLAS

- Very simple signature (and analysis)
- Photon identification based both on lateral and longitudinal segmentation of the Electromagnetic calorimeter
- Two high-quality isolated high-p_T photons
  - $p_{T1} > 40$ GeV; $p_{T2} > 25$ GeV
  - $|\eta_{12}| < 1.37$ and $1.52 < |\eta_{12}| < 2.37$



Sampling 3

Sampling 2

Sampling 1

preshower

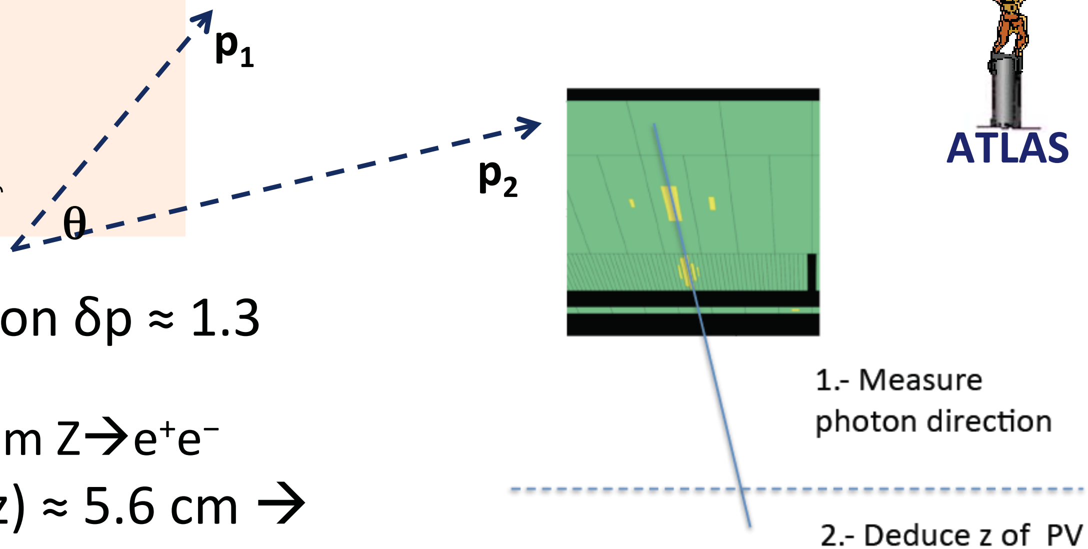
Spring 2011 data

H→γγ – mass reconstruction

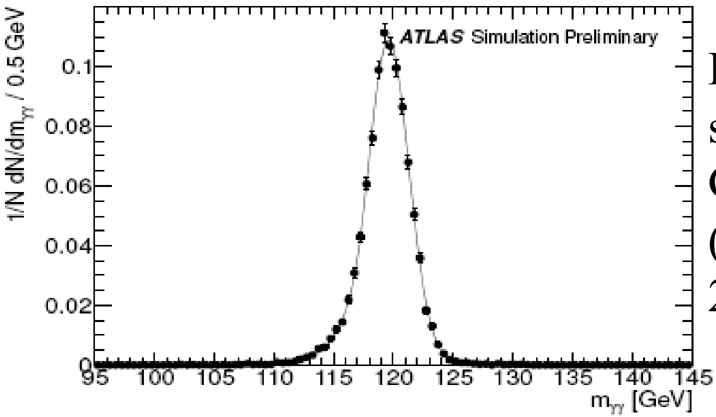
Mass reconstruction

$m^2 = 2P_1P_2(1-\cos\vartheta) \cong P_1P_2\vartheta^2$

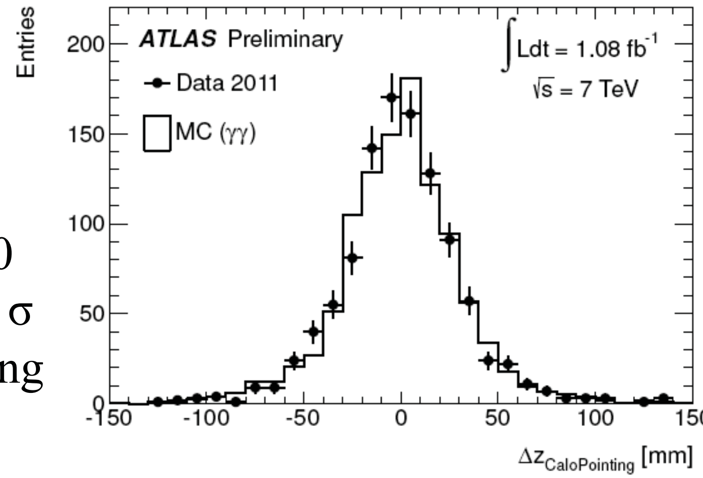
$\delta m/m = (1/\sqrt{2})(\delta P/P) \oplus \delta\vartheta/\vartheta$



- Energy resolution contribution $\delta p \approx 1.3$ GeV
  - Energy scale calibration from $Z \rightarrow e^+e^-$
- Interaction point spread: $\sigma(z) \approx 5.6$ cm → $\delta m\,(\theta) \approx 1.4$ GeV
- Resolution with pointing: $\sigma(z) \approx 1.5$ cm



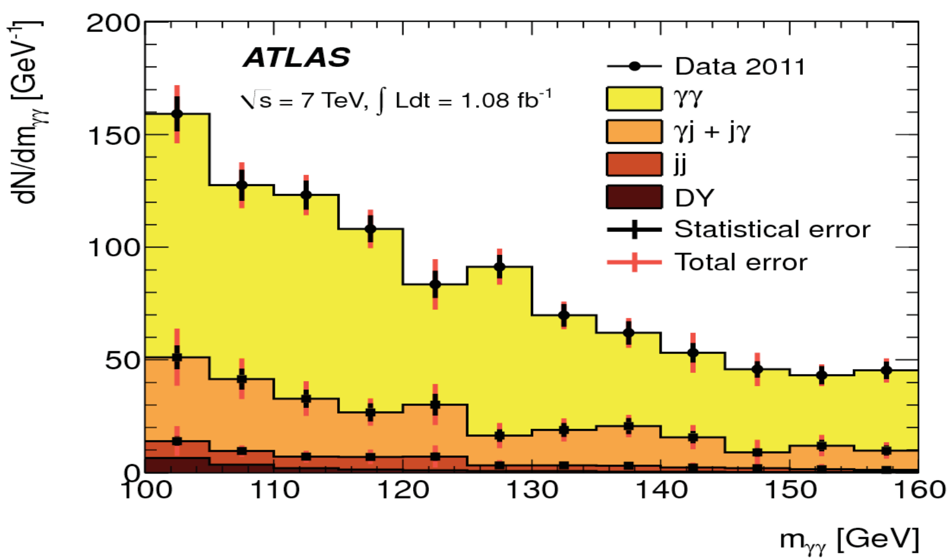
Distribution of simulated $m_H = 120$ GeV Higgs events; $\sigma(m) \sim 1.7$ GeV (using 2010 calibration)

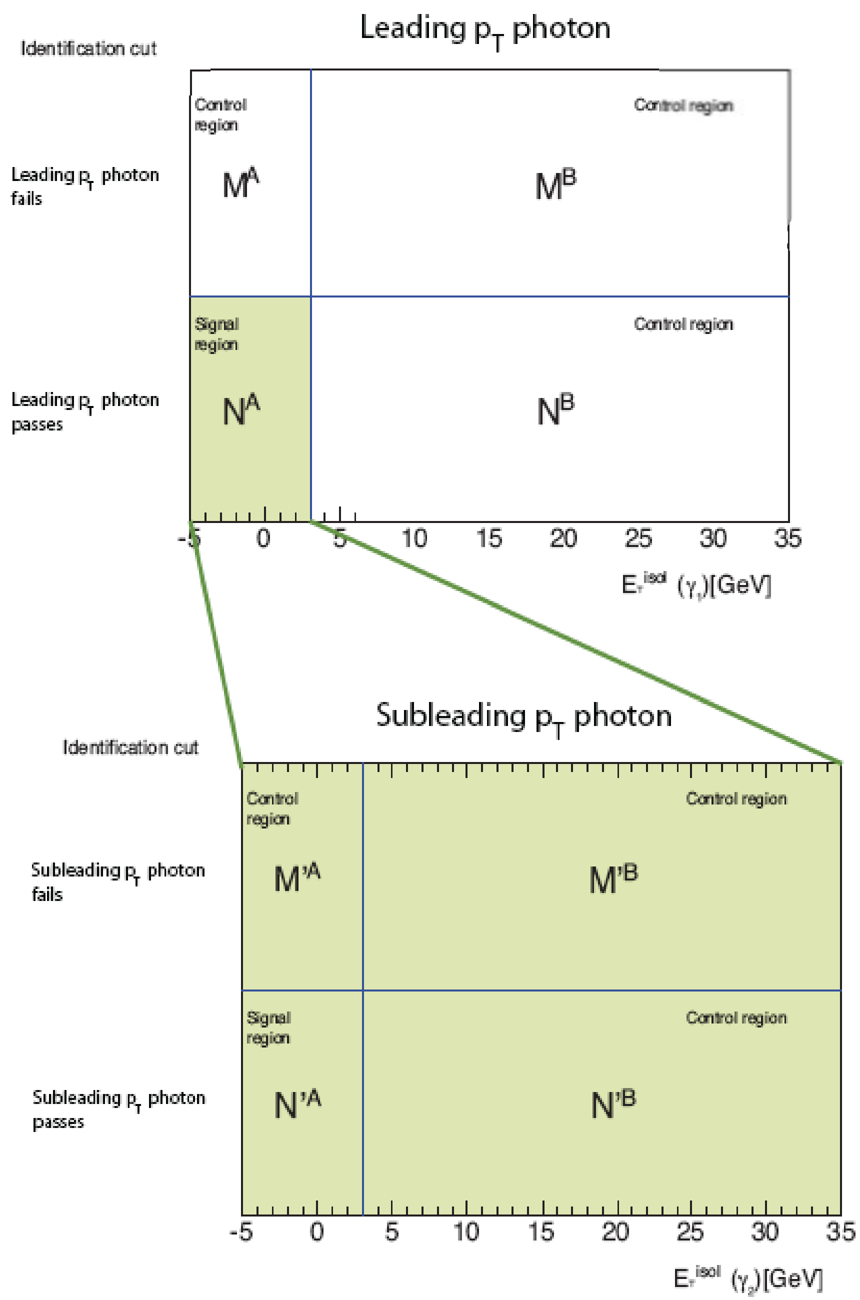


$\Delta z_{12} = z_{\gamma 1} - z_{\gamma 2}$; $\Delta z_{12} \approx 3$ cm; → $\delta z_{\gamma\gamma} \approx 1.5$ cm;

H→γγ – results

- Measure the SM background using control samples
  - analyze photon isolation and identification criteria (loose-tight) to extract the γγ, γj, and jj components
- Perform the analysis of the data classifying the events in 5 categories
  - these are based on the direction of the photons in η and on whether they are converted-unconverted





Associated production H→bb

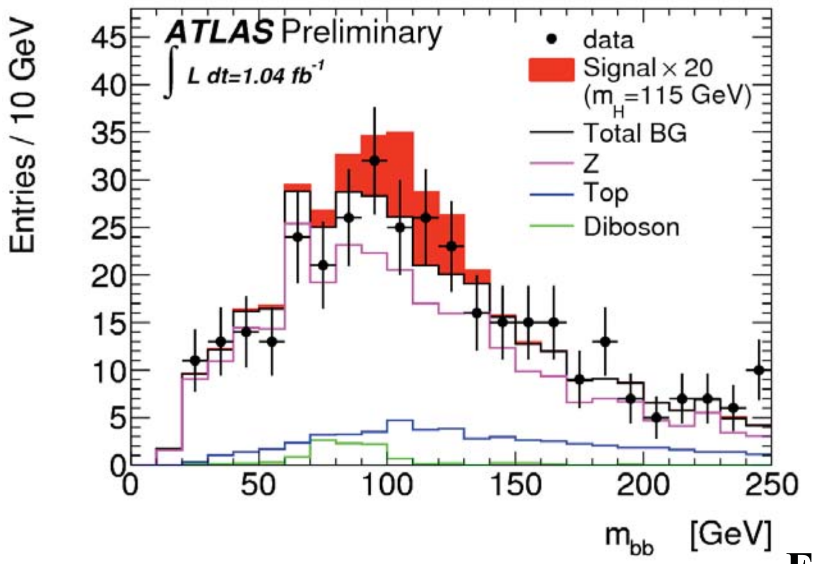
ATLAS

- The decay of the SM Higgs boson to bb final states is of particular importance as it is one of the few channels that offer experimentally the possibility of measuring directly Higgs to quark couplings;
- It may play also an important role in the search of this boson in the low mass region
- It is the dominant decay mode at low mass, but the QCD jet background makes this search impossible in the inclusive channel, while it is very promising in the production in association with W,Z and ttbar

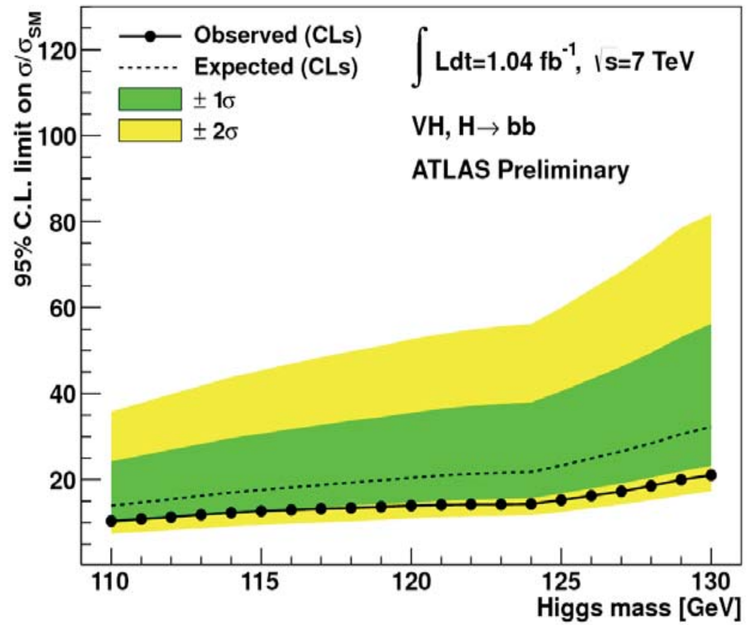
W,Z+H→bb – event selection

- Select events with Z or W boson in the leptonic final state (used also to trigger the event), and with exactly twob-tagged jets with p_T>25 GeV
- Backgrounds:
  - W+jets, Z+b-jets, top, QCD jets

ATLAS



The invariant mass, m_{bb}, for ZH→llbb, for m_H=115 GeV; The signal distribution enhanced by a factor of 20 for visibility.



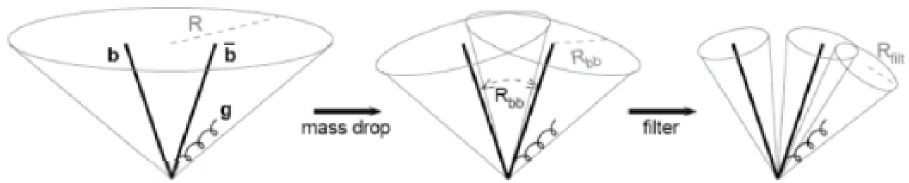
Expected (dashed) and observed (solid line) exclusion limits for the VH(→bb) channels combined. Exclude 10-20 x SM prediction

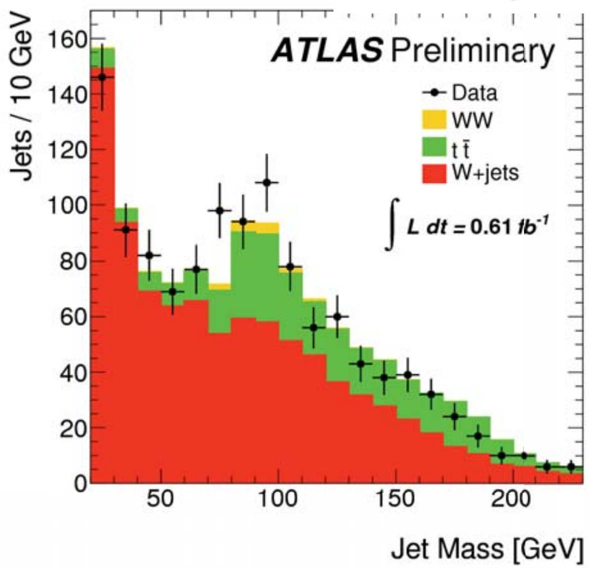
Improve the sensitivity to H→bb decays by looking to events with boosted jet pairs

W,Z+H→bb – boosted Higgs

- Improve the sensitivity to H→bb decays by looking to events with boosted jet pairs
  - For p_T^H >200 GeV it represents only a 5% of the total yield but the background is strongly suppressed
- Reconstruct "fat" jets, using algorithms with cone sizes as large as R=1.2
- Analyse the structure of this jet, and reconstruct sub-jets with smaller R sizes; use these re-clustered jets to reconstruct the jet system invariant mass

ATLAS





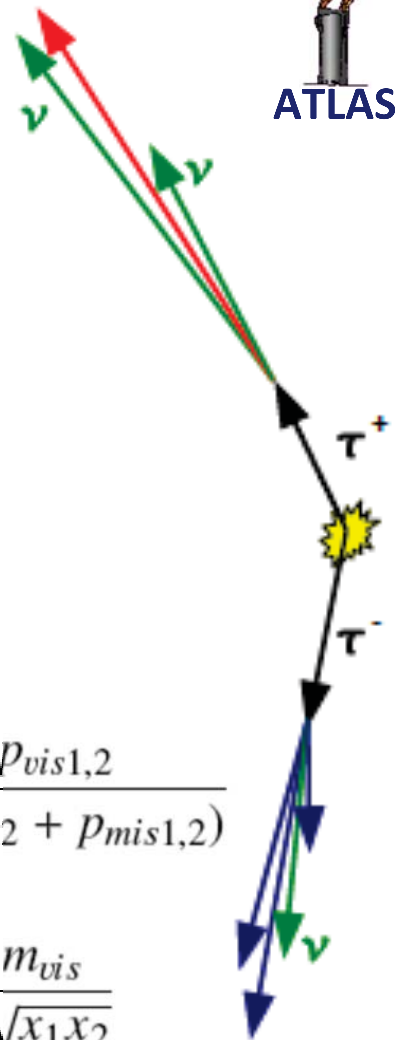
jet mass distribution of subjets with p_T>180 GeV in events consistent with a WH→lνbb boson decay with p_T>200 GeV. The distribution is compared to the uncorrected MC simulation prediction for ttbar, W+jets and WW processes.

The observed peak is consistent with W→jj decays; proof of principle in real data for future Higgs to b-final states analyses

H→ττ

- Promising channel for SM Higgs searches in the mass range m_H=110-140 GeV
  - The VBF production offer the advantage of a small background, at the price of a low signal production rate
- Three classes of final states, depending on the τ-decay:
  - lepton-lepton, ll (l=e, μ)
  - lepton-hadron, lh
  - hadron-hadron, hh
- ATLAS has studied the ll and lh final states
- Most important backgrounds:
  - Z/γ* → ll + jets (→ττ is largely irreducible); W→lυ + jets; dibosons, ttbar and single top, QCD jets
- Selection for ll:
  - 2e, or 2μ or 1e1μ with $p_T^e > 15$ GeV $|\eta^e|<2.47$; $p_T^\mu > 10$ GeV $|\eta^\mu|<2.5$; opposite charge required
  - At least 1 jet with $p_T^j > 40$ GeV $|\eta^j|<4.5$;
  - $E_T^{miss} > 30$ GeV for 2e and 2μ, > 20 for 1e1μ
- ll final state: reconstruct the tau momentum in the collinear approximation
- Apply dilepton invariant mass and topological cuts
- ➔ Study the tau-tau invariant mass

ATLAS

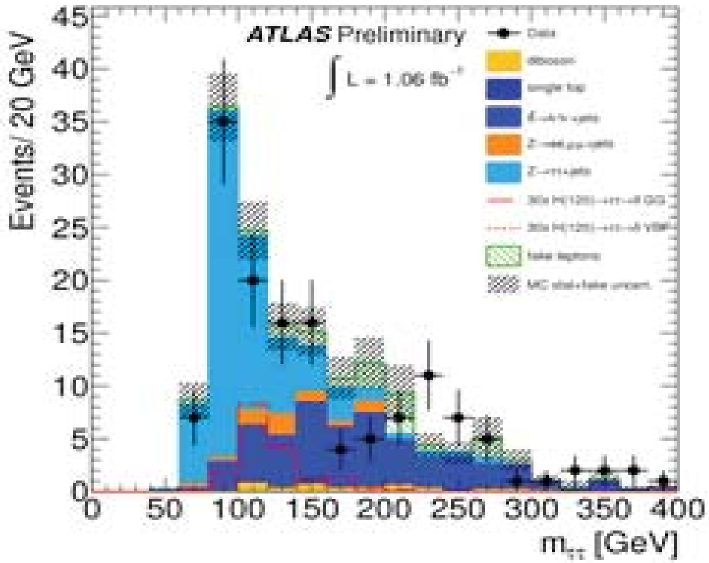


$$x_{1,2} = \frac{p_{vis1,2}}{(p_{vis1,2} + p_{mis1,2})}$$

$$m_{\tau\tau} = \frac{m_{vis}}{\sqrt{x_1 x_2}}$$

Collinear approximation

H→ττ



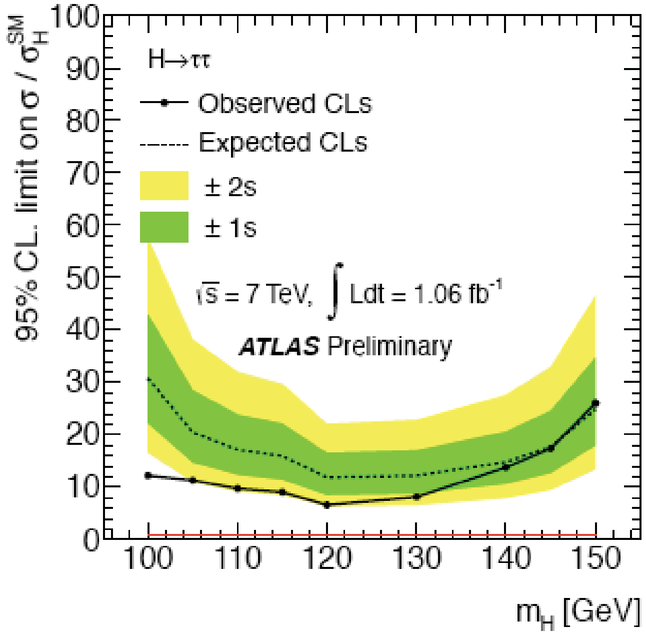
$m_{\tau\tau}$ invariant mass after all cuts ee, μμ and eμ channels. The QCD jets, W+jets and Z/γ→ τ+τ− contributions are estimated from data. All other contributions are estimated using simulated event samples.

	yield
observed	46
expected	47.4±3.9
gg→H(120 GeV)	0.44±0.05
VBF H(120 GeV)	0.38±0.02

Systematic uncertainties:

- Dominated by the Jet Energy Scale (JES)
- Important contribution also from E_T^{miss}

ATLAS



Expected and observed 95% C.L. exclusion limits for neutral Higgs boson production in the SM as a function of m_H.

$H \rightarrow WW^{(*)} \rightarrow l\nu l\nu$ ($l=e,\mu$)

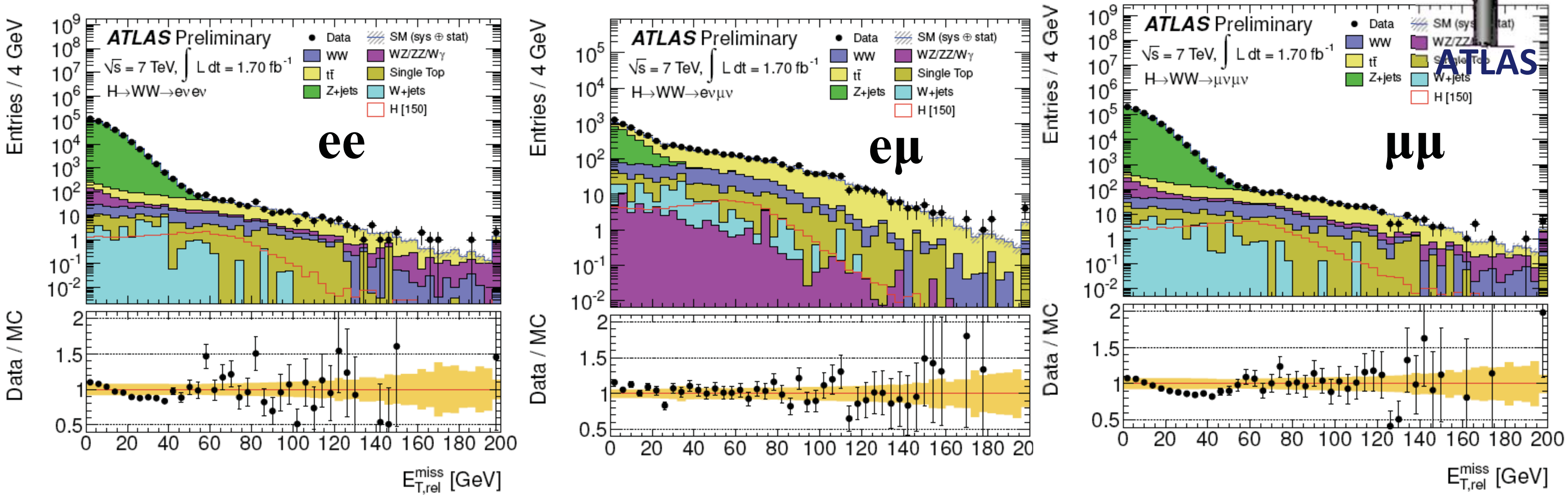
ATLAS

- The most sensitive process for $130 < m_H < 200$ GeV
- But also one of the most challenging channels: complete reconstruction of the invariant mass of this final system not possible
- Largest background is the irreducible WW SM production
  - But also Drell-Yan and top process when looking to final states associated to one jet
- Select events with two high-p_T opposite sign leptons and large transverse missing energy (E_T^{miss})

	e-e	μ-μ	e-μ
pT leading, GeV	25	25	25
pT subleading, GeV	20	15	e:15, μ:20
$E_{t,rel}^{miss}$	40	40	25

$$E_{\mathrm{T,rel}}^{\mathrm{miss}} = \begin{cases} E_{\mathrm{T}}^{\mathrm{miss}} & \text{if } \Delta\phi \geq \pi/2 \\ E_{\mathrm{T}}^{\mathrm{miss}} \cdot \sin\Delta\phi & \text{if } \Delta\phi < \pi/2 \\ & \Delta\phi = \min(\Delta\phi(E_{\mathrm{T}}^{\mathrm{miss}}, \ell),\ \Delta\phi(E_{\mathrm{T}}^{\mathrm{miss}}, j)) \end{cases}$$

H→WW(*)→lνlν – event selection



Distributions of E_T^{miss}rel after lepton p_T cuts

	WW	$Z/\gamma^* + \text{jets}$	$t\bar{t}$	$tW/tb/tqb$	$WZ/ZZ/W\gamma$	Total Bkg.	Observed
$m_{\ell\ell} > 15$ GeV, $m_{e\mu} > 10$ GeV	$1,380 \pm 100$	$970,000 \pm 70,000$	$6,200 \pm 600$	630 ± 70	$1,200 \pm 100$	$970,000 \pm 70,000$	997813
$\lvert m_Z - m_{\ell\ell} \rvert > 15$ GeV	$1,220 \pm 80$	$91,000 \pm 7,000$	$5,500 \pm 600$	560 ± 60	92 ± 9	$98,000 \pm 7,000$	104253
$E_{\mathrm{T,rel}}^{\mathrm{miss}}$	660 ± 50	300 ± 200	$2,700 \pm 300$	310 ± 40	28 ± 4	$4,000 \pm 500$	4051

Data/MC agreement at this stage better than 10%, within systematic uncertainties

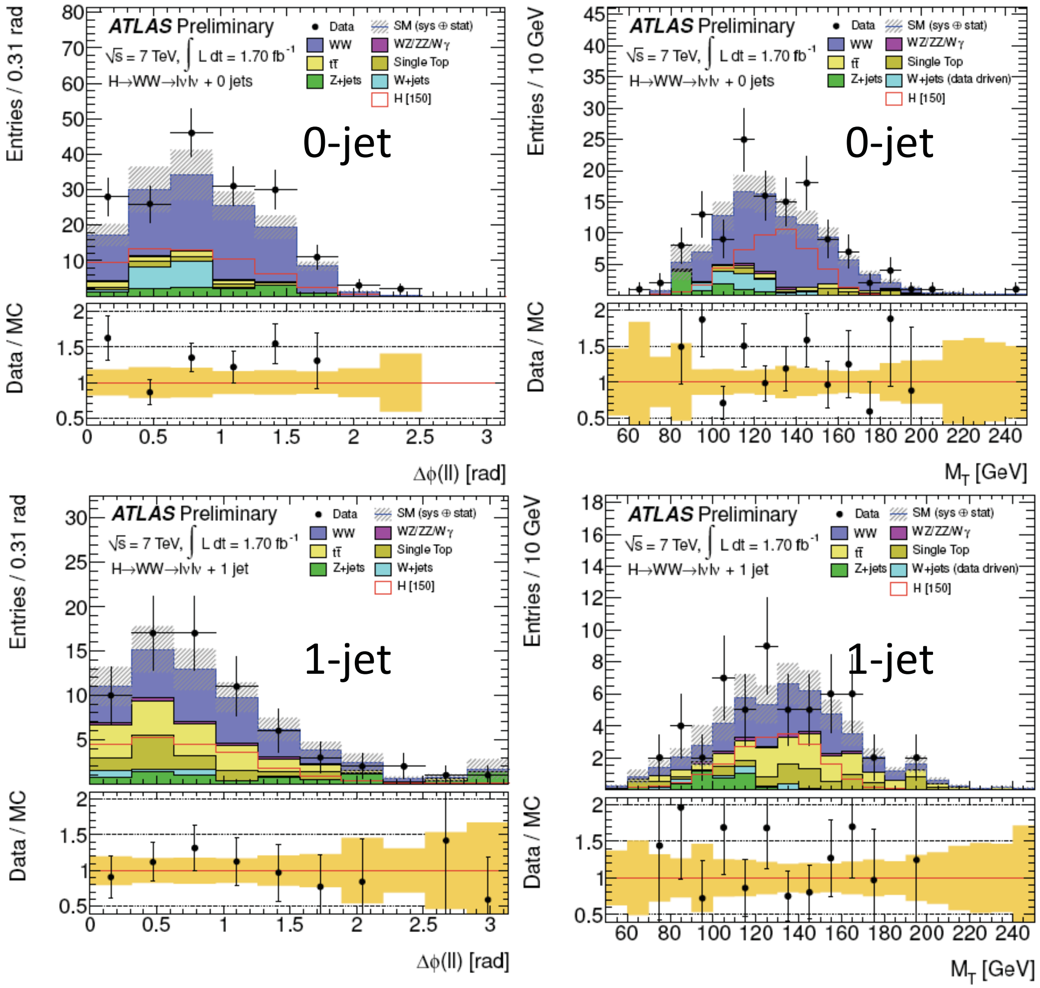
H→WW$^{(*)}$→lνlν – event selection

ATLAS

- After $E_t^{miss}{}_{,rel}$ cut, divide the events in two categories:
  1. Events with 1 jet with p_T>25 GeV and |η|<4.5;
  2. Events with no jets
- Apply topological cuts (p_T^{ll}, $\Delta\varphi^{ll}$)
- Reconstruct the transverse mass m_T and apply the cut $0.75\times m_H < m_T < m_H$

$$m_{\mathrm{T}} = \sqrt{(E_{\mathrm{T}}^{\ell\ell} + E_{\mathrm{T}}^{\mathrm{miss}})^2 - (\mathbf{P}_{\mathrm{T}}^{\ell\ell} + \mathbf{P}_{\mathrm{T}}^{\mathrm{miss}})^2}$$

H→WW$^{(*)}$→lνlν – event selection



dilepton azimuthal angle after p_T^{ll} and m^{ll} cuts

Transverse mass after all cuts (except m_T itself)

Final selection, optimized for m_H=150 GeV

	WW	ttbar	Total SM back.	Data	Higgs m_H=150
0-jet	43±6	2.2±1.4	53±9	70	34±7
1-jet	10±2	6.9±1.9	23±4	23	12±3

Event yield after full selection, in data and MC (W+jets estimated with data driven methods). The cuts are here optimized to select m_H=150 GeV Higgs decays.

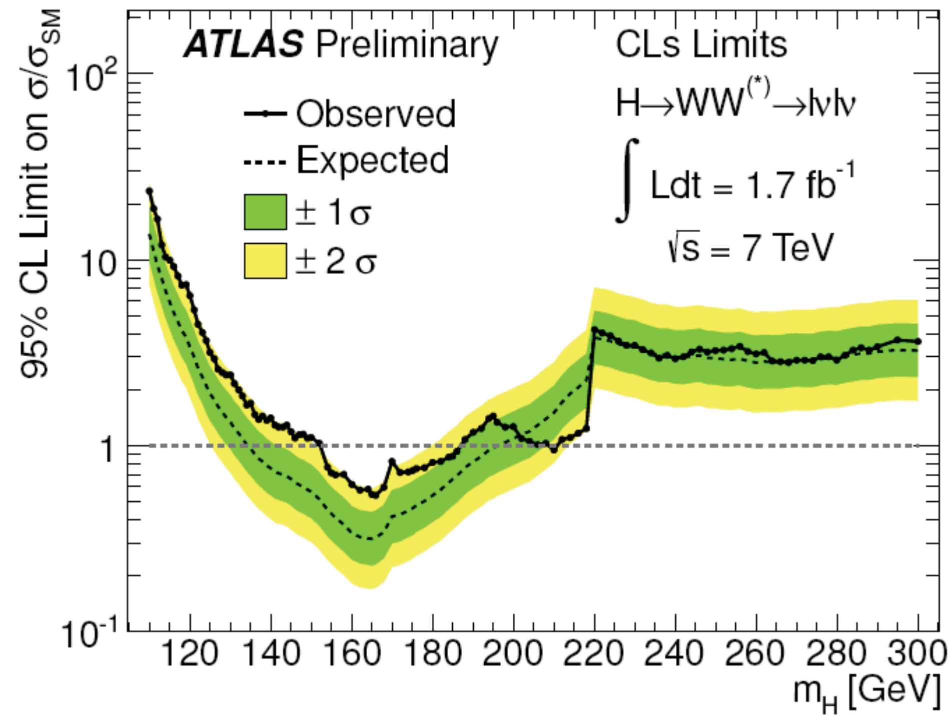
H→WW$^{(*)}$→lνlν – background estimate

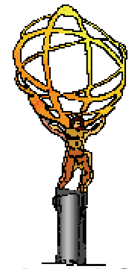
- Background estimate from data in counting experiment is essential
- In the current version of this analysis we estimate from data the two largest backgrounds, namely those from WW and top
  - Approach:
    - Define control regions rich in WW or top backgrounds and measure this backgrounds in data
    - Extrapolate this measurement to the signal region(s) using MC shapes
- W+ jets entirely determined from data
- Remaining backgrounds (smaller) are taken from MC
  - Apply scale factor to Drell-Yan for potential E_T^{miss} mis-modelling

$$N^{S.R.}_{data} = \alpha \times N^{C.R.}_{data}, \qquad \alpha = \frac{N^{S.R.}_{MC}}{N^{C.R.}_{MC}}$$

Control Region	MC expectation	Observed
WW 0-jet	250±50	237
WW 1-jet	139±18	144
Top 1-jet	350±100	316

H→WW$^{(*)}$→lνlν – exclusion limit





H+ 0-jet and H+1-jet bins

The expected (dashed) and observed (solid) 95% C.L. upper limits on the cross-section, normalized to the SM cross-section, as a function of the Higgs boson mass.

(the jump in the expected and observed limits at 220 GeV is due to the change in the selection at that point)

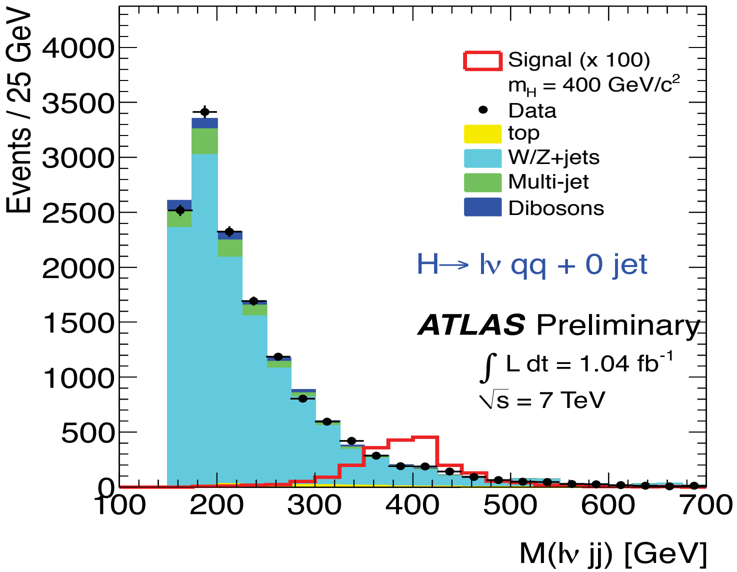
- Since EPS (July 21st): improvements in the analysis (new b-tagging algorithm, cut optimization for m_H>220 GeV) + additional data
- A Standard Model Higgs boson with 154<m_H<186 GeV is excluded at 95% C.L.
  - Expected exclusion mass range is 135<m_H<196 GeV
  - The observed limit is within 2σ of the expected one in the mass range 130 – 150 GeV

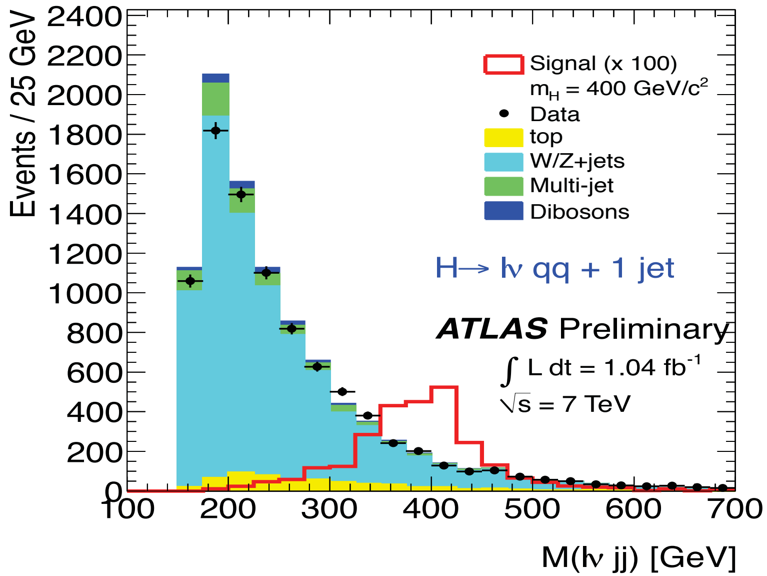
$H \rightarrow WW \rightarrow l\nu qq$ ($l=e,\mu$)

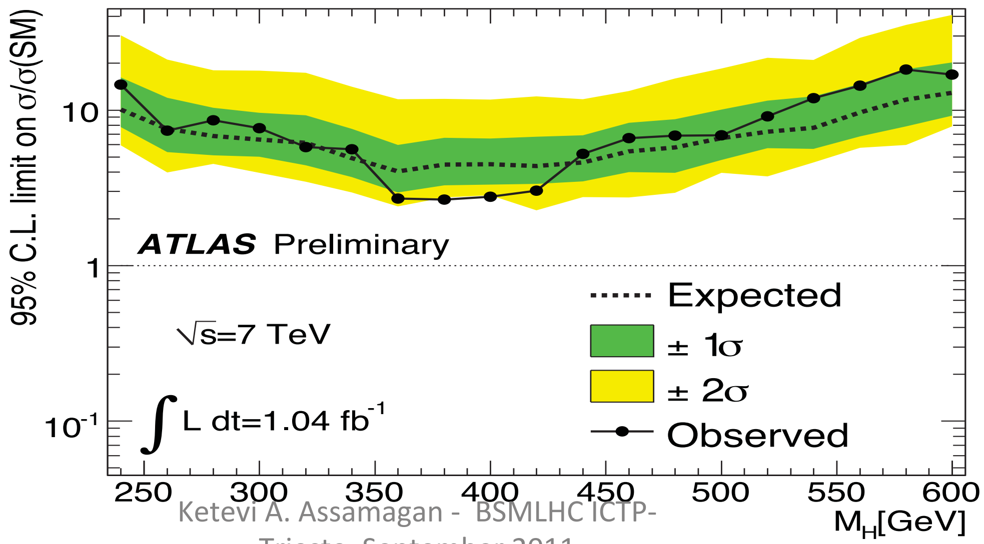
ATLAS

- The channel $H \rightarrow WW \rightarrow l\nu qq$ offers at large values of m_H acceptable signal/background ratio.
- Search performed in the mass region $240<m_H<600$ GeV
- Selection:
  - Exactly one lepton (e or μ) with $p_T>30$ GeV;
  - $E_T^{miss} > 30$ GeV
  - Exactly two or exactly three jets with $p_T>30$ GeV in $|\eta|<4.5$ (Higgs + 0-jet and H + 1-jet bins) with one pair fulfilling $71<m_{jj}<91$ GeV
  - Constrain $m_{l\nu} = m_W$, and $m_{jj} = m_W$. Then, reconstruct the $m_{l\nu qq}$ invariant mass
  - Search for peak in the $m_{l\nu qq}$

H→WW→lνqq







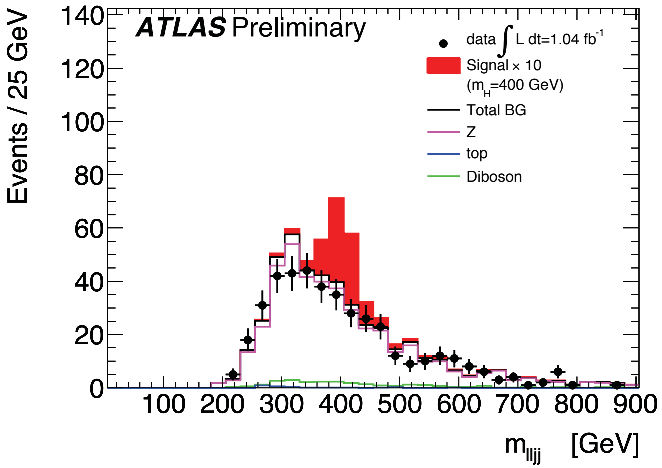
The upper limit at m_H 340 GeV is ≈ 5 × SM prediction

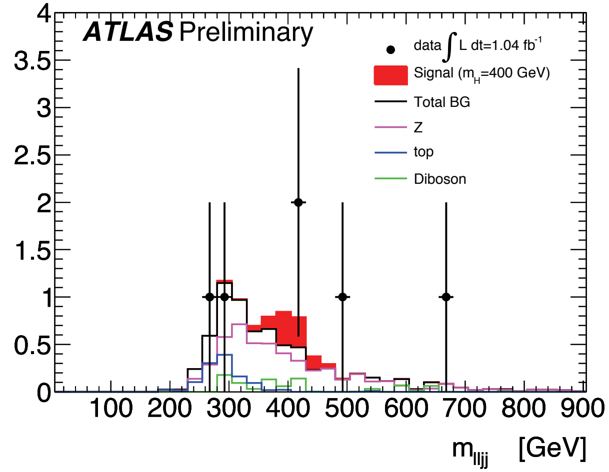
H→ZZ→llqq (l=e,μ)

ATLAS

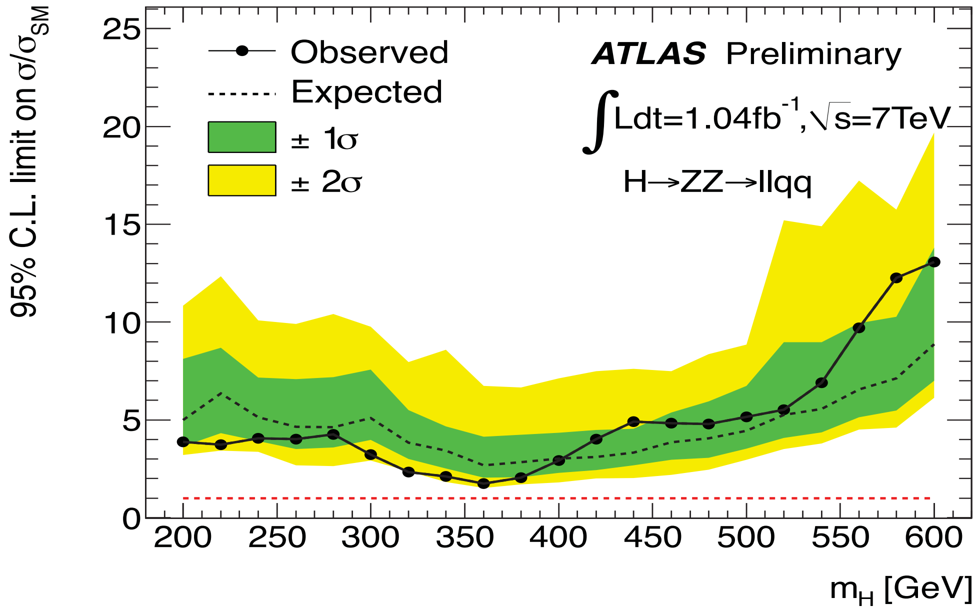
- Very helpful channel in the Higgs mass range $m_H > 2m_Z$, with acceptable signal-to-background ratio
- Signature: Z→ll+2 jets final states
- Main backgrounds: QCD Z+jets
- Event selection:
  - Same flavour pair of isolated leptons with p_T>20 GeV, with 76 <m_{ll}<106 GeV
    - Third lepton veto, E_T^{miss}<50 GeV
  - ≥2 jets p_T>25 GeV |η|<2.5, with 70 <m_{ll}<105 GeV
  - Reconstruct the final state invariant mass m_{lljj} (with m_{jj} scaled to m_Z)

H→ZZ→llqq





The invariant mass of the lljj system for the b-untagged (left) and b-tagged (right) selections, for m_H = 200 and 400 GeV. The Higgs boson signal in the untagged plots has been scaled up by a factor of 10.



- Good sensitivity in a wide mass range
- Observed limit 1.7 x SM for m_H = 360 GeV
- Expected limit between 2.7 – 9 times the SM predictions

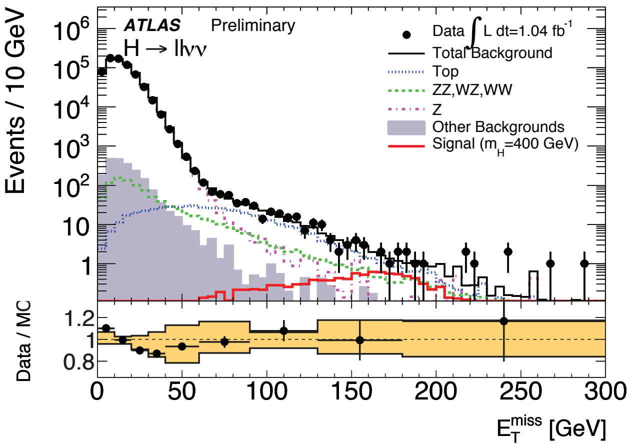
H→ZZ→llνν (l=e,μ)

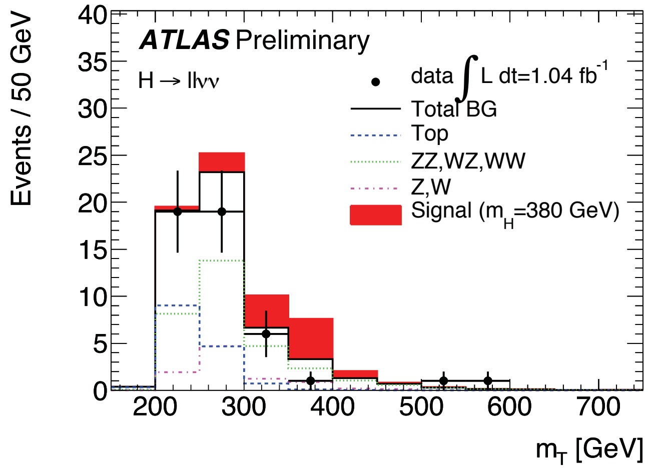
ATLAS

- Final state characterized by the production of a Z in leptons accompanied by large transverse missing energy, it offers a significant branching fraction in combination with a good separation from background processes
- Main background: reducible QCD W/Z+jets, top; irreducible WW,WZ,ZZ
- Select events with two same-flavour opposite charge leptons whose invariant mass is consistent with the Z-mass, and ETMiss > 66(82) GeV depending on the "low'("high") mass analysis
  - Apply also topological cuts to suppress W/Z+jet QCD background
- Finally, study the transverse mass distribution, m_T:

$$m_T^2 \equiv \left[\sqrt{m_Z^2 + |\vec{p}_T^{\,\ell\ell}|^2} + \sqrt{m_Z^2 + |\vec{p}_T^{\,\mathrm{miss}}|^2}\right]^2 - \left[\vec{p}_T^{\,\ell\ell} + \vec{p}_T^{\,\mathrm{miss}}\right]^2$$

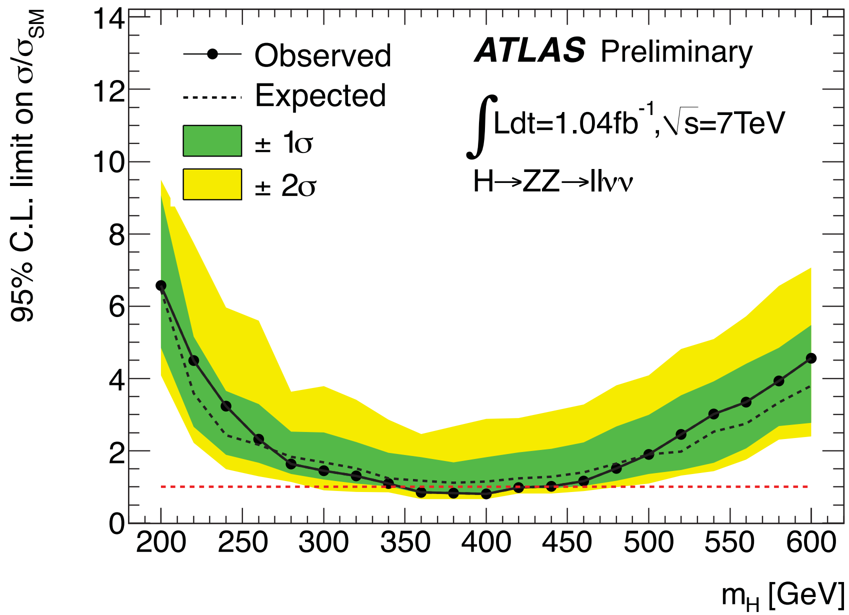
H→ZZ→llνν





Left: E_t^{miss} distribution after the m_{ll} window cut.

Right: the dilepton transverse mass distribution of selected candidate events;



- A Standard Model Higgs boson in the range 350 GeV < m_H < 450 GeV, is excluded at the 95% confidence level

$H \rightarrow ZZ^{(*)} \rightarrow 4l$ ($l=e,\mu$)

ATLAS

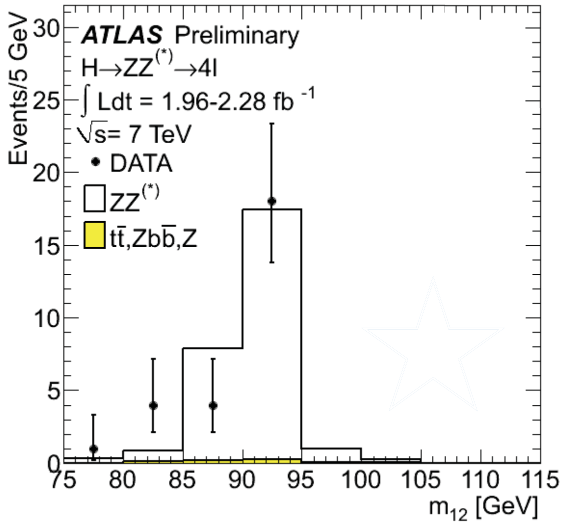
- The "gold-plated" channel
- Very clean, but small rates
- Backgrounds: irreducible ZZ(*); reducible Z+jets (in particular Zbb), ttbar
- Event selection simple:
  - Trigger: inclusive high-pt electron or muon;
  - Two isolated same-flavour opposite charge lepton pairs. Each lepton with $p_T > 7$ GeV. In the region between barrel and end-cap calorimeters, electron $p_T > 15$ GeV. At least 2 with $p_T > 20$ GeV
  - Reconstruct the Z (mass window cut)
  - Veto low invariant mass pairs
  - For $m_{4l} < 2m_Z$ require also small lepton impact parameter

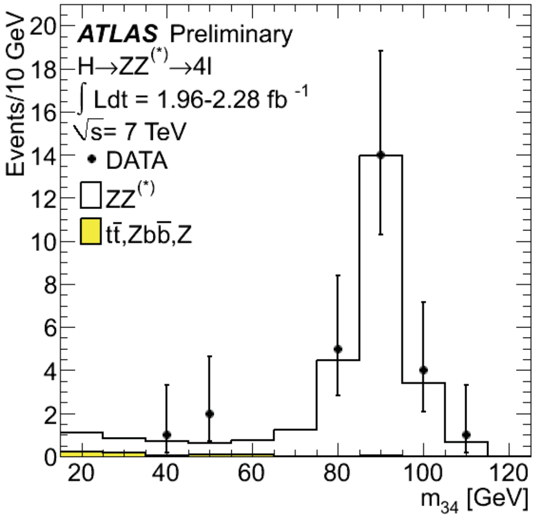
$H \rightarrow ZZ^{(*)} \rightarrow 4l$

ATLAS

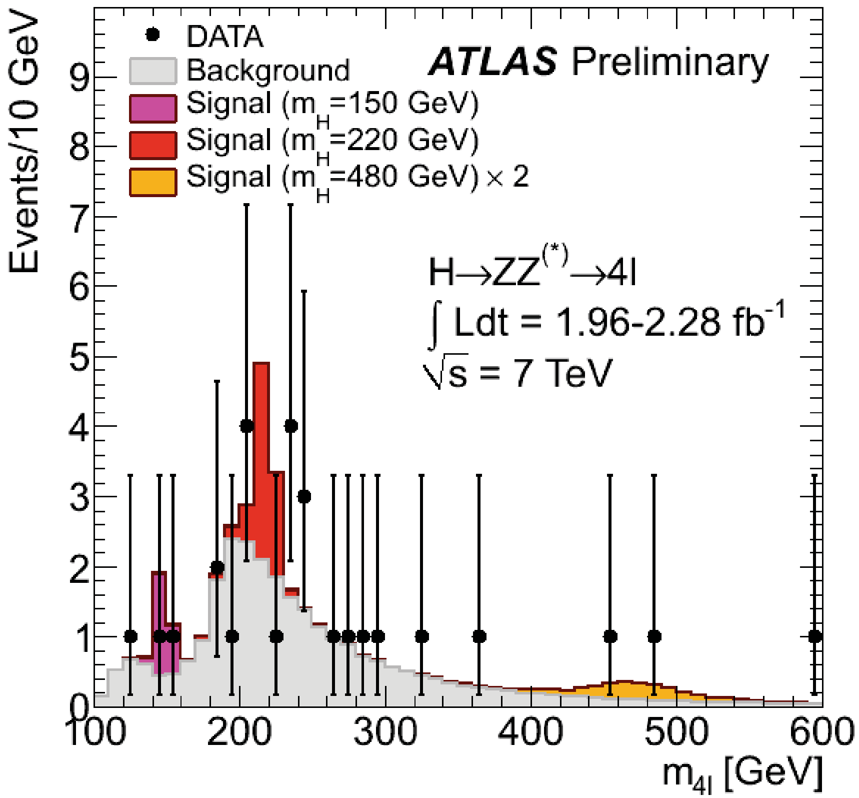
- Background estimates:
  - $ZZ^{(*)}$ from MC prediction (including both qq/qg→ZZ and gg→ZZ)
    - Theory uncertainty: 15%
  - Top from MC prediction
    - Yield validated in control region
    - Theory uncertainty 10%
  - Z+jets normalized to data using control regions
    - Control region: clean Z + 2nd lepton pair with no isolation and impact parameter requirements
    - Uncertainty: 20-40% (dominated by statistics in control regions and extrapolation to signal region)

H→ZZ(*)→4l

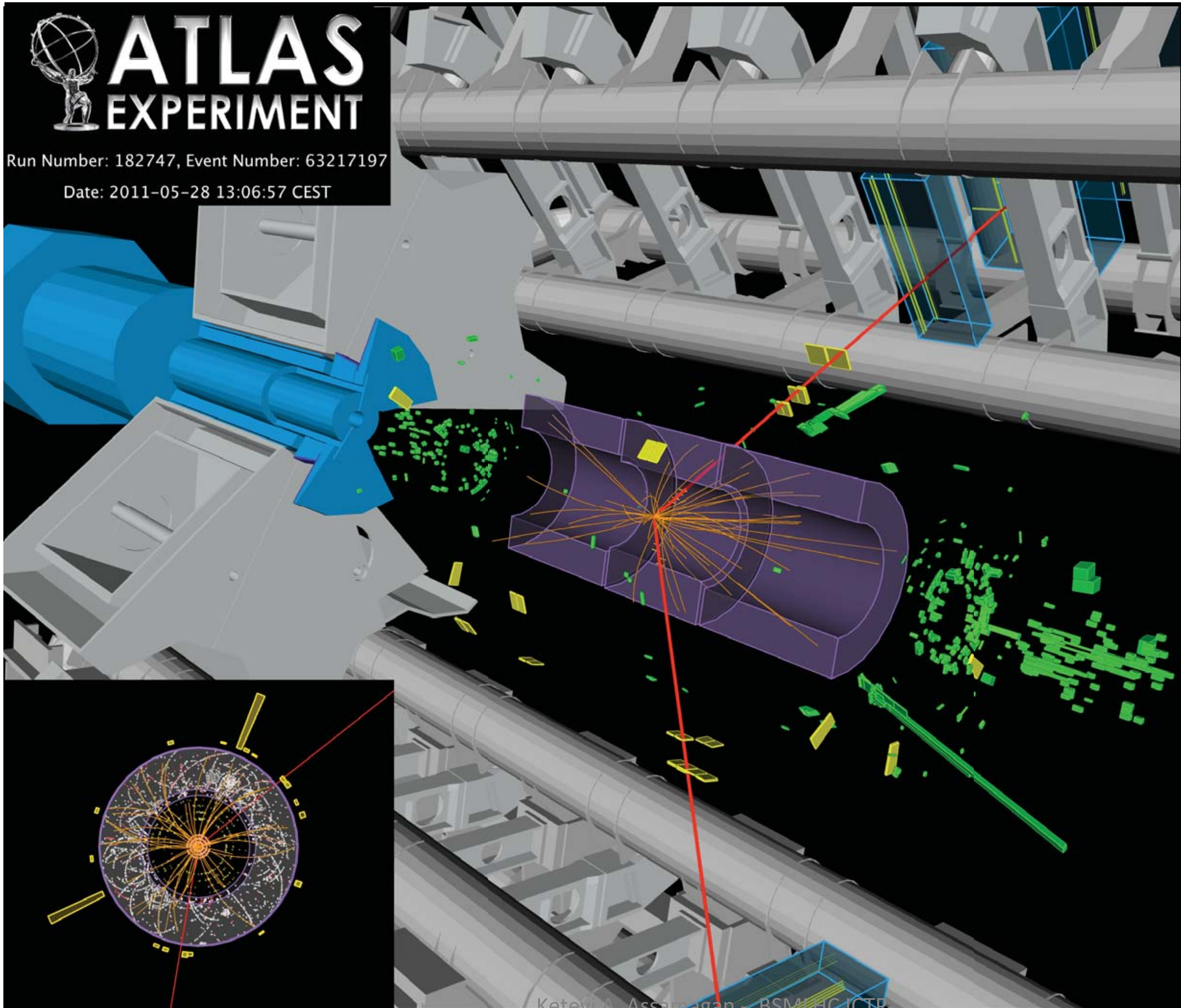




Invariant mass leading (top) and sub-leading (bottom) lepton pair



- A total of 27 events are selected by the analysis algorithm: 6ee, 9eμ, 12μμ
- Expected: 28±4



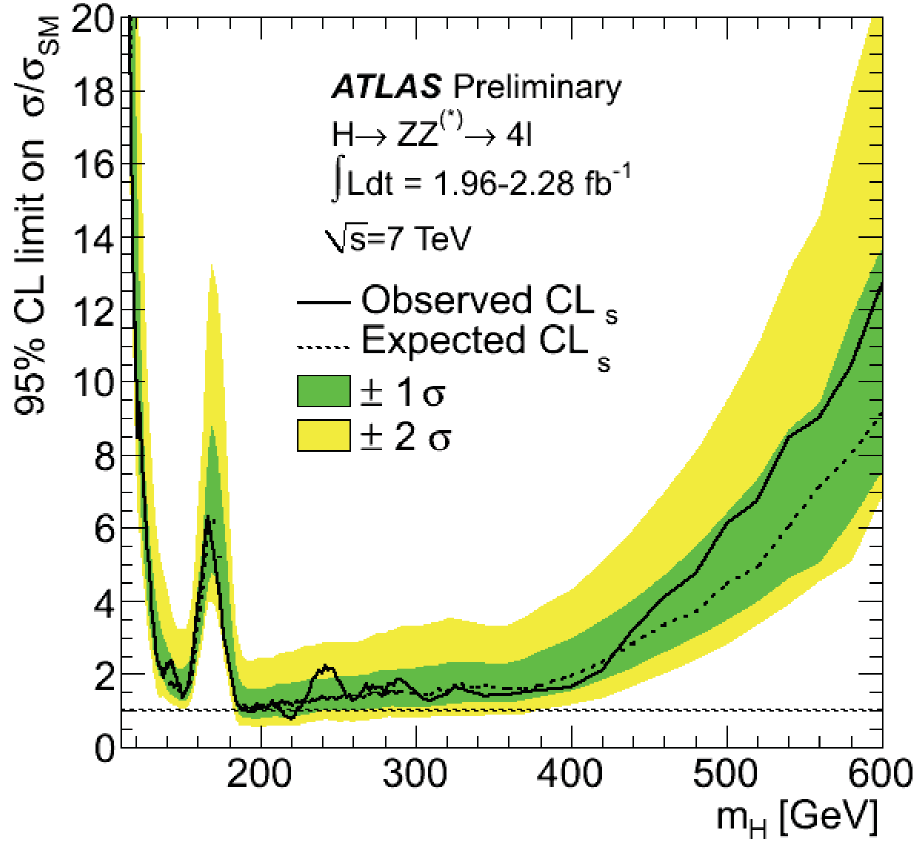
2μ2e candidate:

m_{lead}: 85.9 GeV

m_{subl}: 85.5 GeV

m_{4l}: 210 GeV

H→ZZ$^{(*)}$→4l- exclusion limits

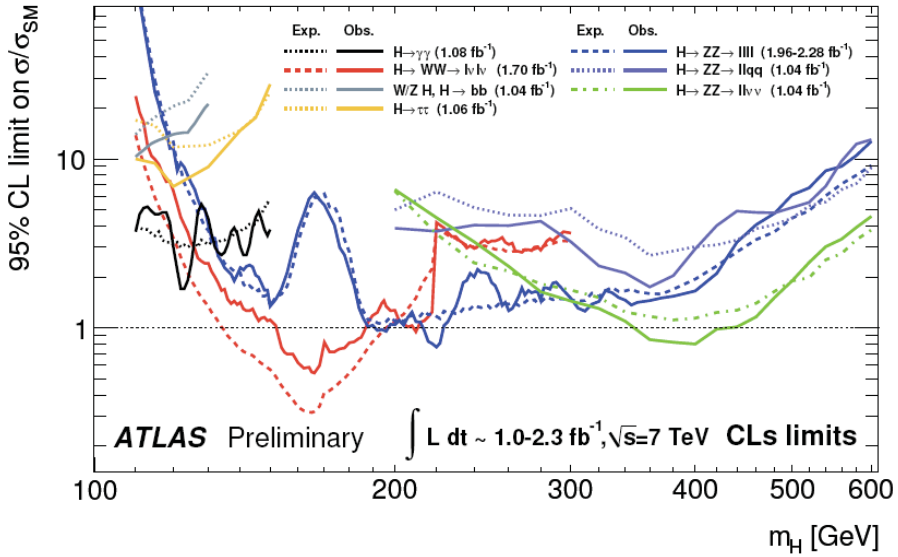


- Very close the SM cross-section
- Some Higgs mass values already excluded around m_H = 200 GeV

ATLAS SM Higgs Combination

Channels used in the Combination:

1. *H→ γγ*
2. *VH,H→bb*
3. *H→ττ*
4. *H→WW(*)→lνlν*
5. *H→ZZ(*)→llll*
6. *H→ZZ(*)→llνν*
7. *H→ZZ(*)→llqq*

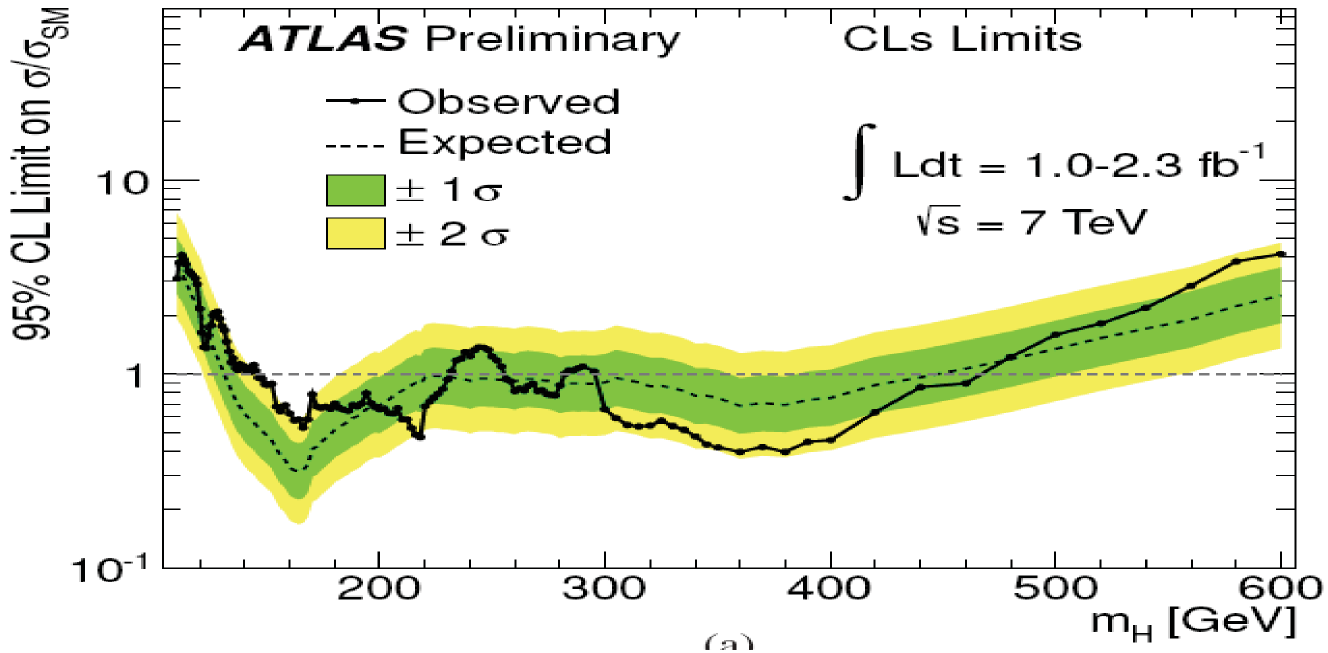


The expected (dashed) and observed (solid) cross-section limits for the individual search channels, normalized to the Standard Model Higgs boson cross section, as functions of the Higgs boson mass.

- Correlated uncertainties (Jet Energy Scale, Luminosity, etc) taken into account
- In other cases, e.g. background estimated via data-driven methods, the uncertainties are uncorrelated
- Careful treatment of theory uncertainties; Higgs boson cross-section uncertainties in QCD scale and PDF+αs taken into account. PDF uncertainty is fully correlated among different channels and it is included in the combination.

ATLAS SM Higgs Combination

ATLAS



The combined upper limit on the Standard Model Higgs boson production cross section divided by the Standard Model expectation as a function of m_H is indicated by the solid line. This is a 95% CL limit using the CLs method in the entire mass range.

Standard Model Higgs boson mass excluded at 95% C.L.:

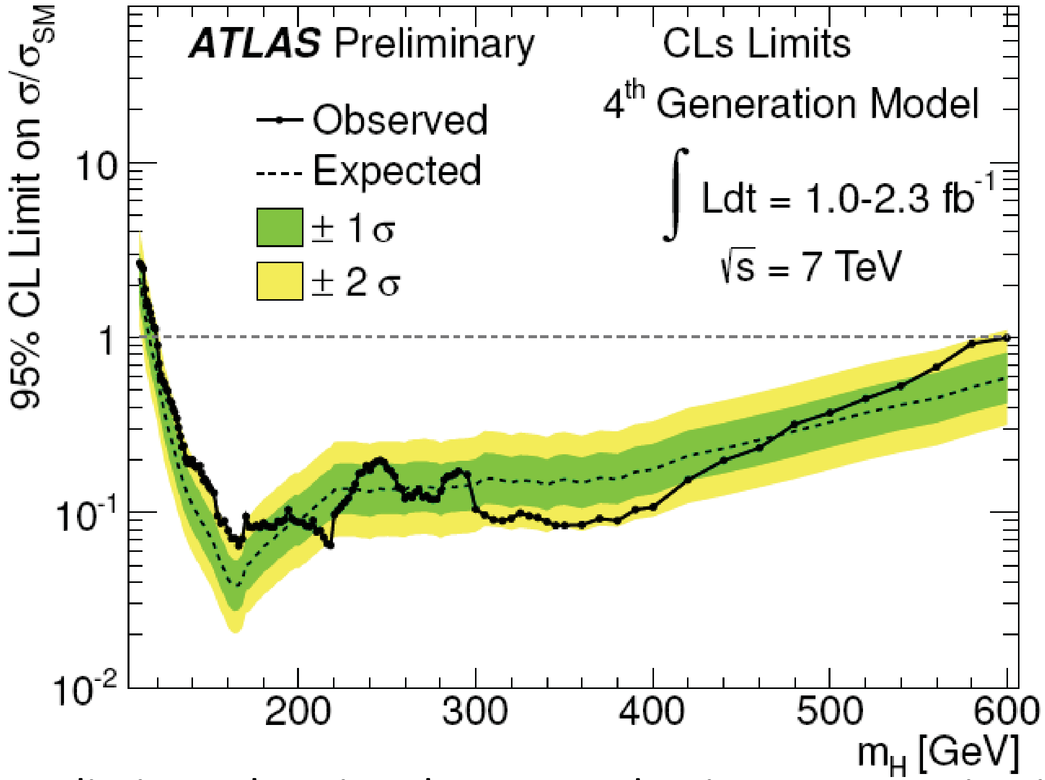
146<m_H<232, GeV

256 <m_H< 282 GeV

296 <m_H< 466 GeV

The exclusion Confidence Level (CLs) is about 99% in the region between 160 GeV and 220 GeV and exceeds 99% between 300 GeV and 420 GeV

Higgs limits assuming a 4th generation heavy fermions

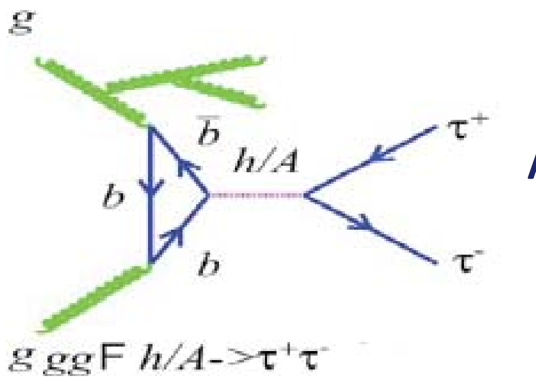


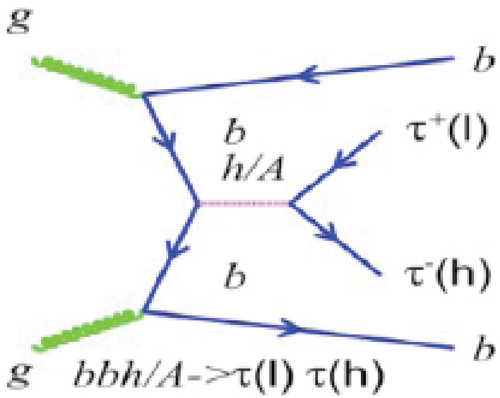
The combined upper limit on the Higgs boson production cross section in the framework of a Standard Model with the addition of a heavy fourth generation of fermions divided by its expectation as a function of m_H is indicated by the solid line. This is a 95% CL limit using the CLs method.

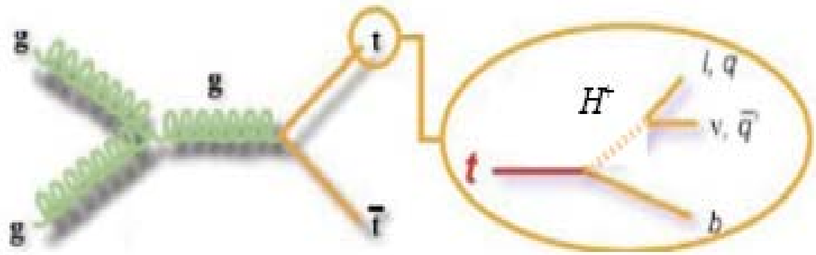
MSSM Higgs

ATLAS

- MSSM Higgs sector
  - 5 bosons h/H/A, H^+, H^-
  - Higgs sector: determined by two parameters; at tree level: tan β and m_A (or m_{H+})
- Major production modes:
  - h/H/A: gg-fusion, b-associated
  - Light H^+: top quark decays
  - *[Heavy H^+: gg/gb-fusion]*
- Dominant decay modes
  - h/H/A → ττ
  - H^+ → τν, for small tan β: H^+ → cs

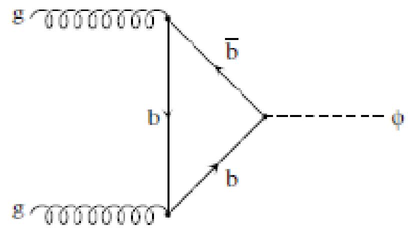


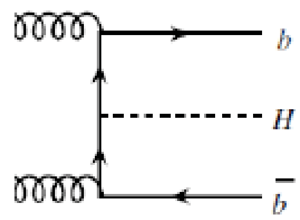




MSSM H/A → ττ

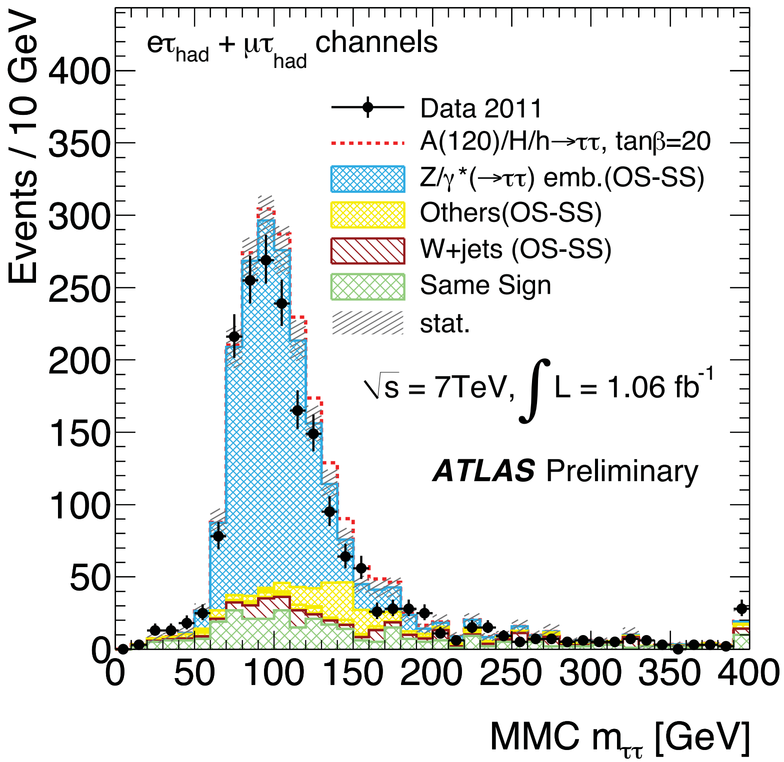
- In MSSM the decay of neutral Higgs to tau-lepton pairs strongly enhanced for large regions of the parameter space: ➔ H/A/h→ττ is one of the most promising channels for Higgs searches at the LHC
- Production: gg→A/H/h and associated bbA/H/h
- Study the final states:
  - H→eμ4ν
  - H→$e\tau_{had}3\nu$, $\mu\tau_{had}3\nu$
  - H→$\tau_{had}\tau_{had}2\nu$
- Event selection: ask high-p_T, isolated leptons, large E_t^{miss}, good quality high-pT hadronic taus
  - More sophisticated method than the collinear approximation to evaluate the $m_{\tau\tau}$ mass is used for $l\tau_{had}$ final states

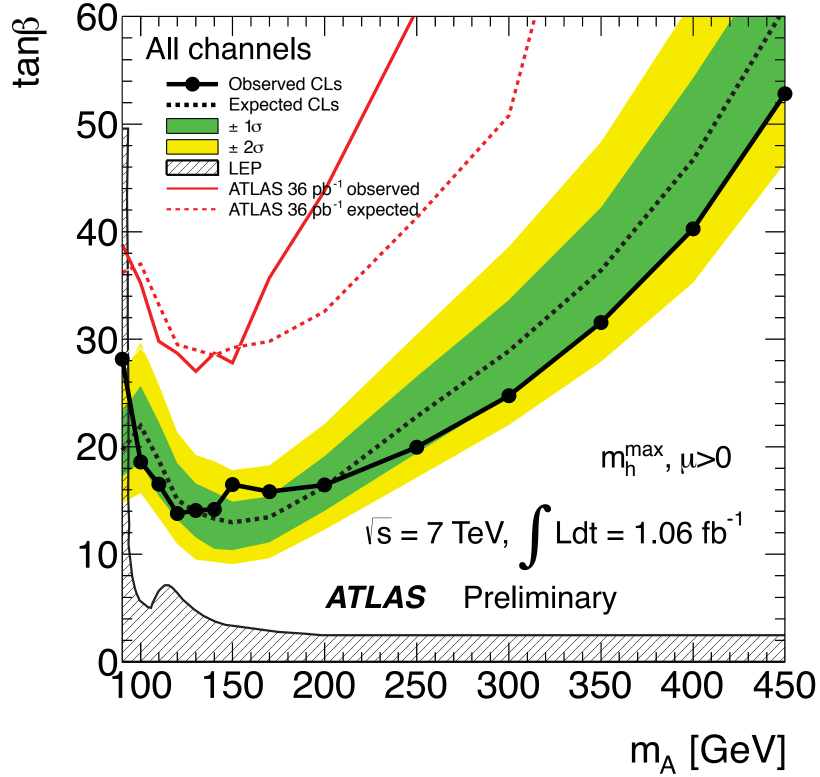




$gg \to b\bar{b}H$

MSSM H/A → ττ





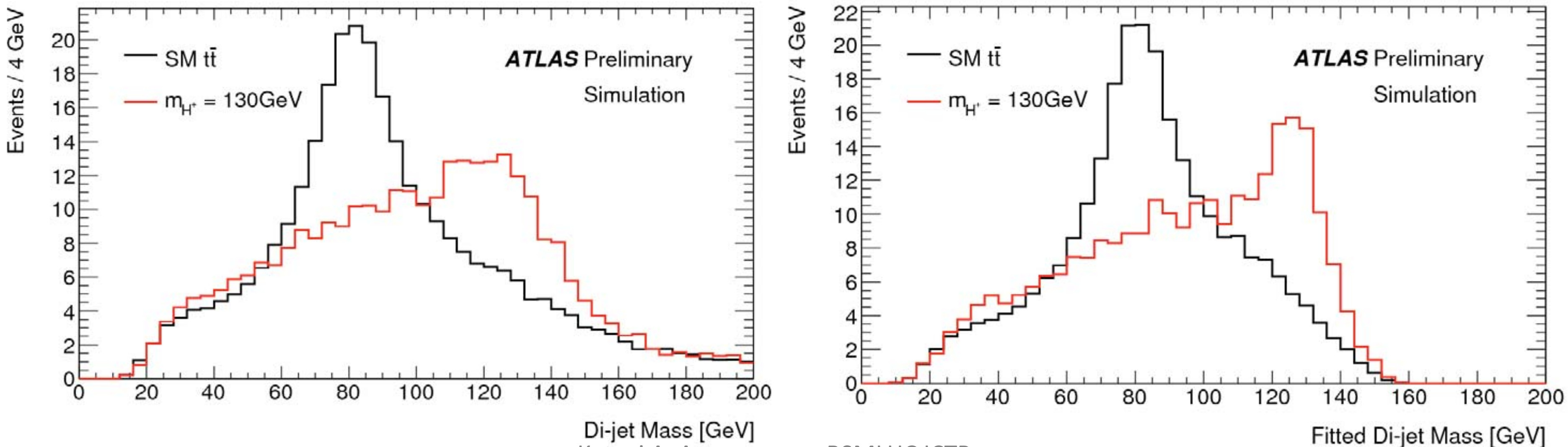
Effective mass distribution for $l\tau_{had}$. The data are compared with the background expectation and an added hypothetical signal. "OS-SS" denotes the difference between the opposite-sign and same-sign event yields.

Expected and observed exclusion limits based on CLs in the m_A – tan β plane of the MSSM derived from the combination of the analyses for the eμ, $l\tau_{had}$ and $\tau_{had}\tau_{had}$ final states. The dark green and yellow bands correspond to the ±1σ and ±2σ error bands, respectively.

t→b (H^+→cs)

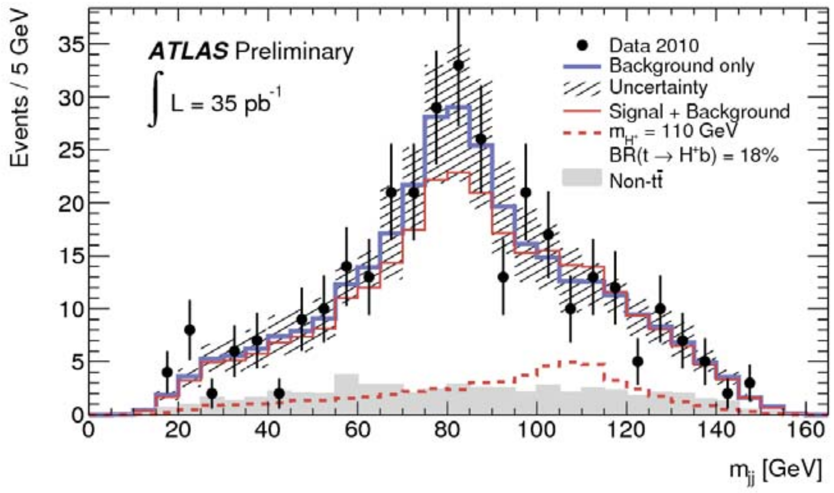
- Selection: high-p_T isolated lepton, large E_T^{miss}, ≥4 jets, ≥1 b-tag jet, m_T consistent with W mass;
- Use an event kinematic fit

Mass peak of the dijet system: MC expectation: before (left) and after (right) event fitter

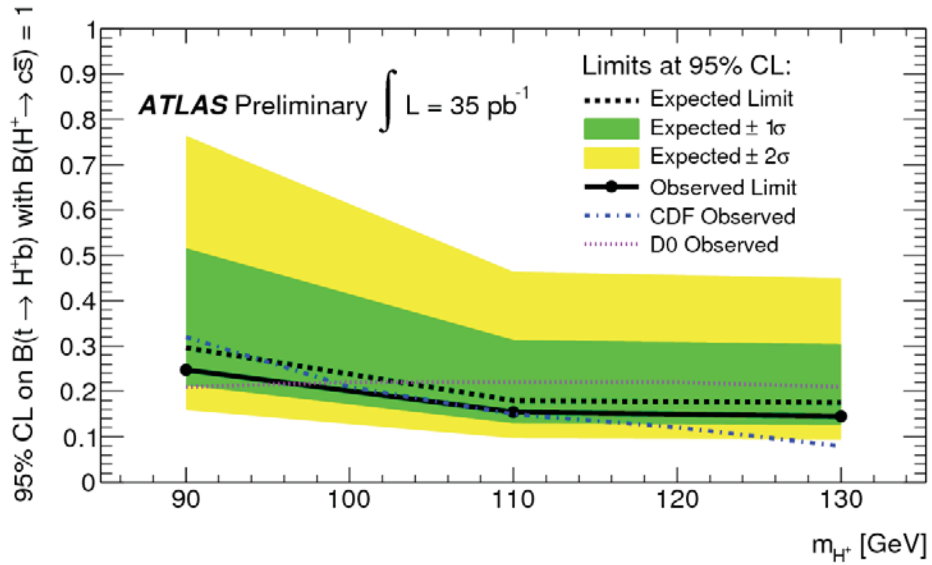


t→H^+b→cs b (using 35 pb^{-1})

Selection: high-p_T isolated lepton, large E_T^{miss}, ≥4 jets, ≥1 b-tag jet, m_T consistent with W mass; use an event kinematic fit



The dijet mass distribution of the data is compared with the expectation from the SM (Br=0) and with the expectation with Br = 0.18 (m_H^+ = 110 GeV).

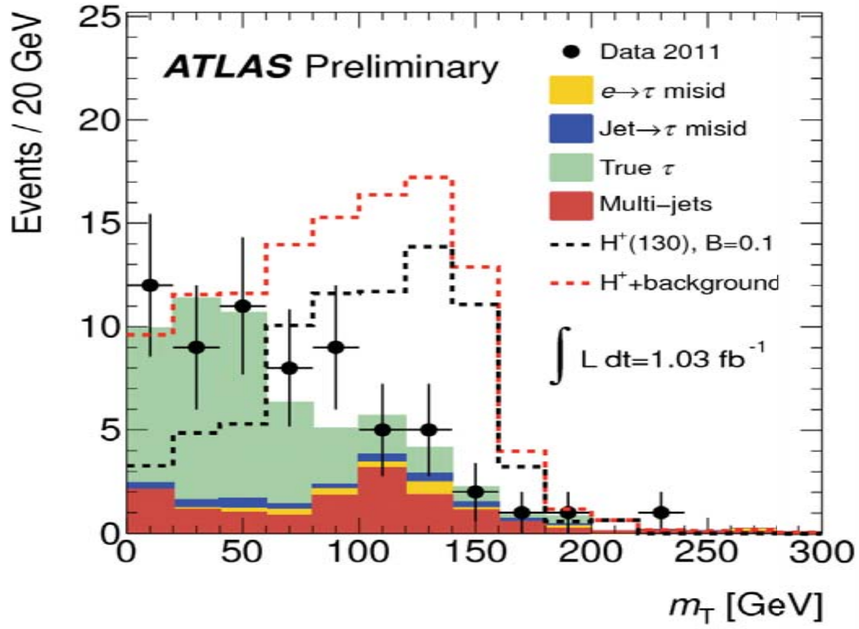


The extracted 95% C.L. upper limits on BR (t→ H^+b) from the ATLAS data are compared with our expected results and results from the Tevatron. The results assume Br(H^+ → cs = 100%). The ATLAS limits shown are calculated using the CL_s limit setting procedure.

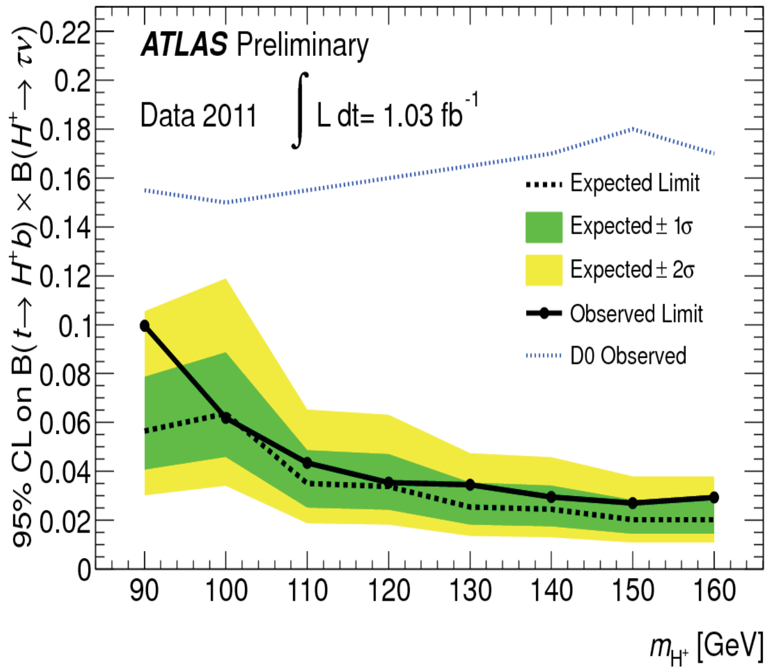
$H^+ \rightarrow \tau\nu$

- Studied in the $\tau \rightarrow l$ and $\tau \rightarrow h$ channels
- Background estimates are all fully data-driven

ATLAS



Transverse mass distribution in the $H^+ \rightarrow \tau\nu$ channel



Exclusion limit on H^+ production as a function of m_{H+}

Conclusions

ATLAS

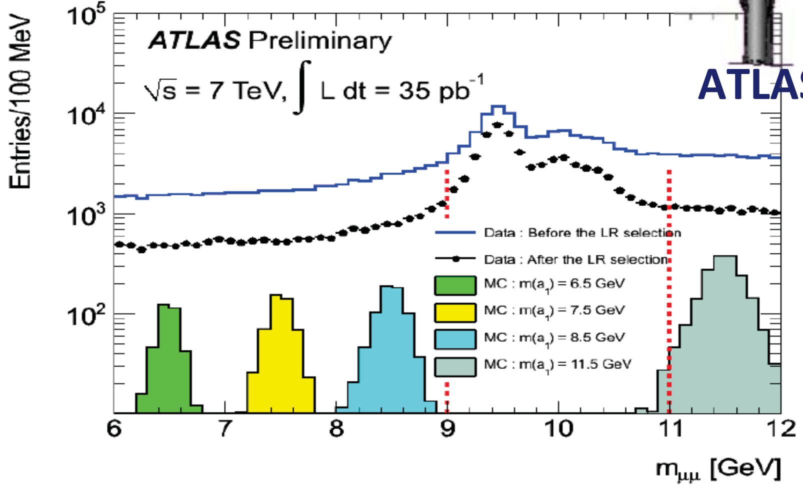
- Proton-proton collisions produced by the LHC and corresponding to an integrated luminosity between 1 and more than 2 fb^{-1} has been analysed by ATLAS to perform Higgs searches
- These data allow to constrain the Standard Model Higgs boson production
- No significant excess (< 2.1σ) is found in the mass range of 110-600 GeV studied by ATLAS; exclusion limits at 95% C.L. are placed in the mass regions:
  - $146 < m_H < 232$ GeV
  - $256 < m_H < 282$ GeV
  - $296 < m_H < 466$ GeV
- More integrated luminosity will definitively help to understand our data, improve the analysis and to increase our sensitivity to a wider mass interval.

BACKUP

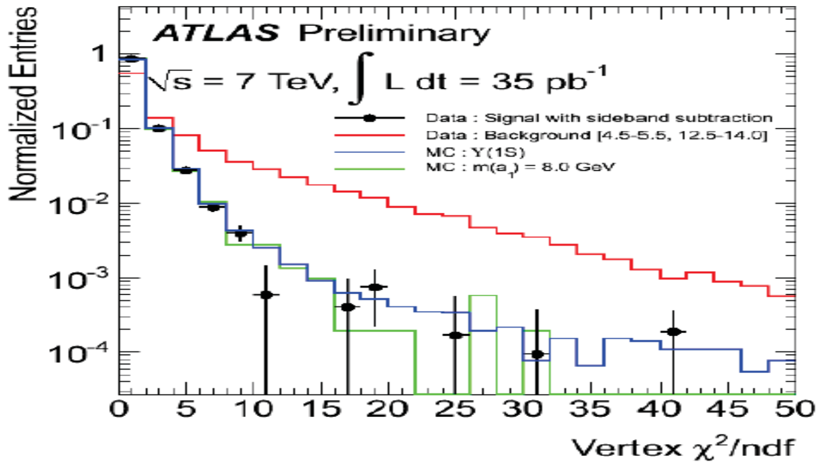
A → μμ at low mass with 35 pb^{-1}

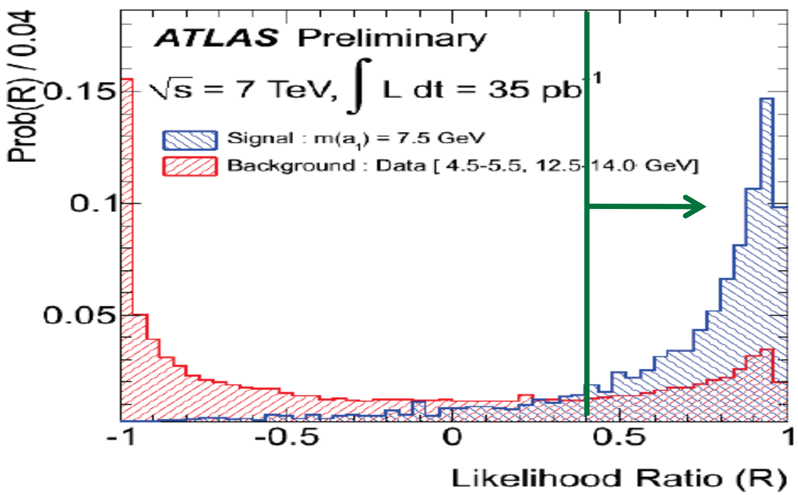
- Search for low mass scalar A in range [6,9] and [11,12] GeV e.g. inspired by NMSSM

- Two muons with p_T>4 GeV (blue line)
- Likelihood ratio selection (black markers)
  - with PDFs derived from data itself
  - signal : 9 to 11 GeV (ϒs and A agree)
  - background: 4.5 to 5.5, 11.5 to 14.5 GeV



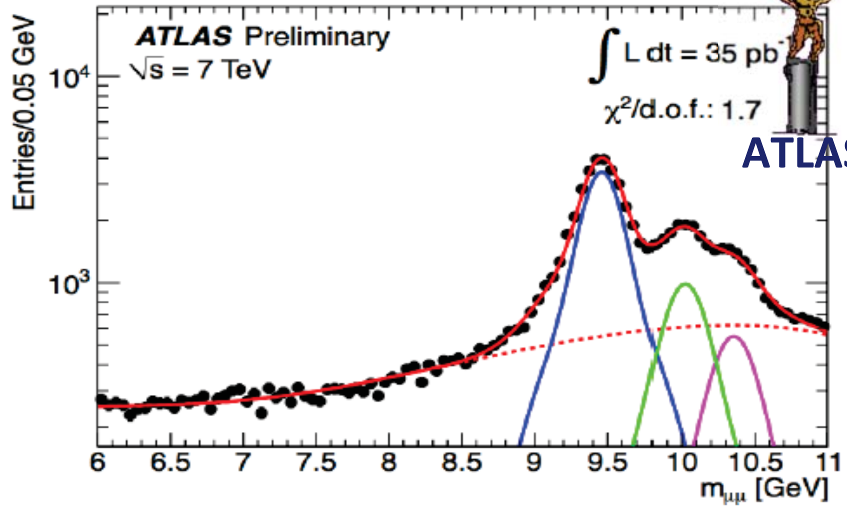
- PDFs for likelihood ratio inputs: primary vertex χ^2/ndf and calo. isolation of muons





A → μμ: Exclusion Limit

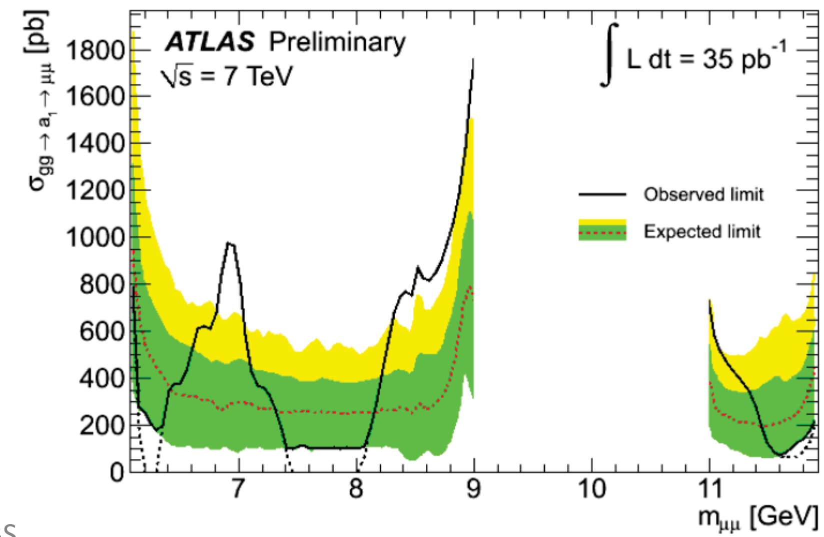
- Limit setting: normalisations floating
  - signal A: double Gaussian with width and fractions of 2 Gaussian related to Υ
  - Υ(1/2/3s) double Gaussian: widths and fractions free parameters, masses fixed to PDG values
  - continuum BG: 4th order Chebyshev polynom with all parameters free



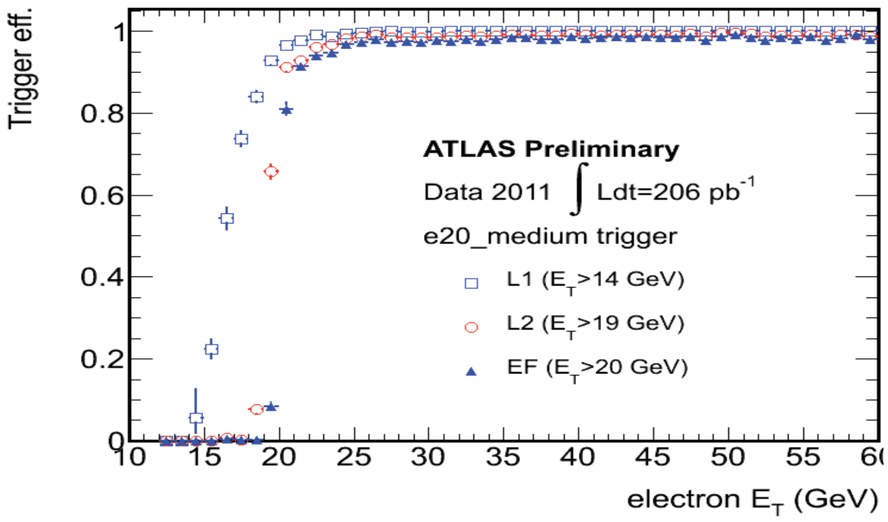
- Signal efficiency uncertainties

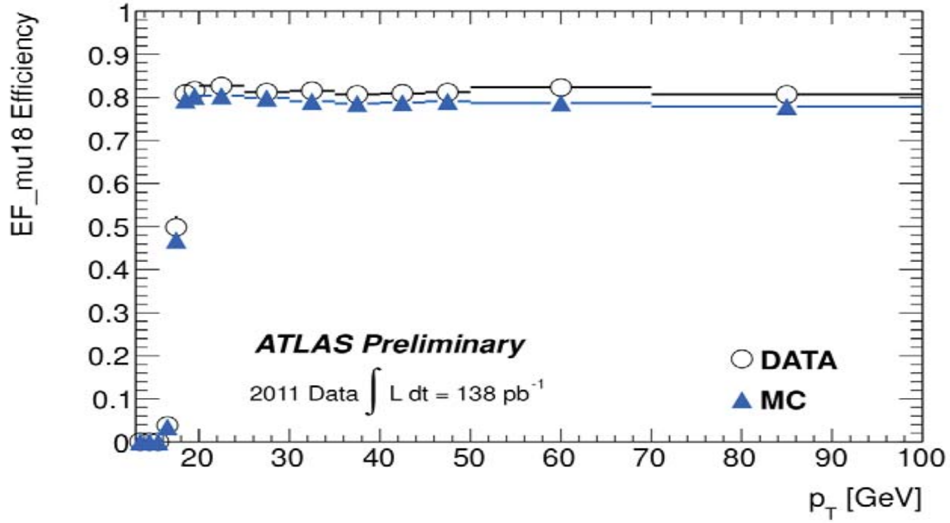
Source	M_A=6(11.5)GeV
Luminosity	3.4 (3.4)%
PYTHIA vs MC@NLO	67 (20)%
Muon Efficiency	14 (15)%
Dimuon Trigger	13 (12)%
Likelihood Method	3 (3) %
Total	70(28)%

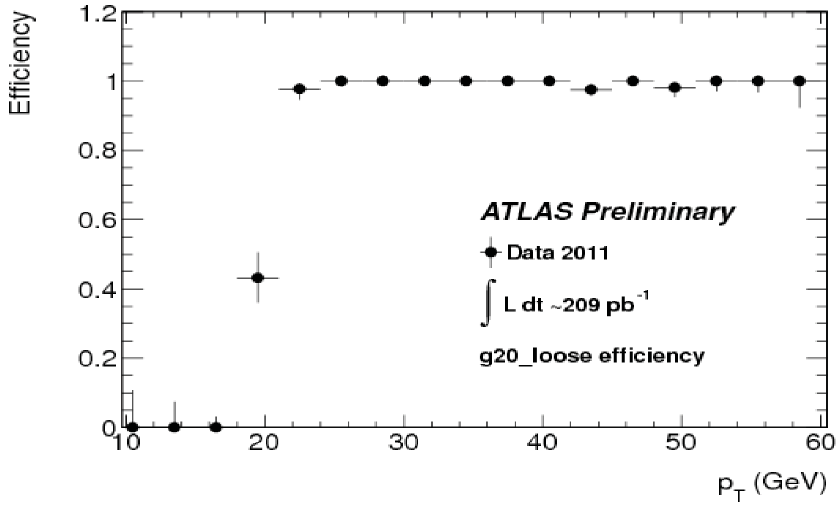
- Limit on σ(gg→A)x BR(A→μμ)

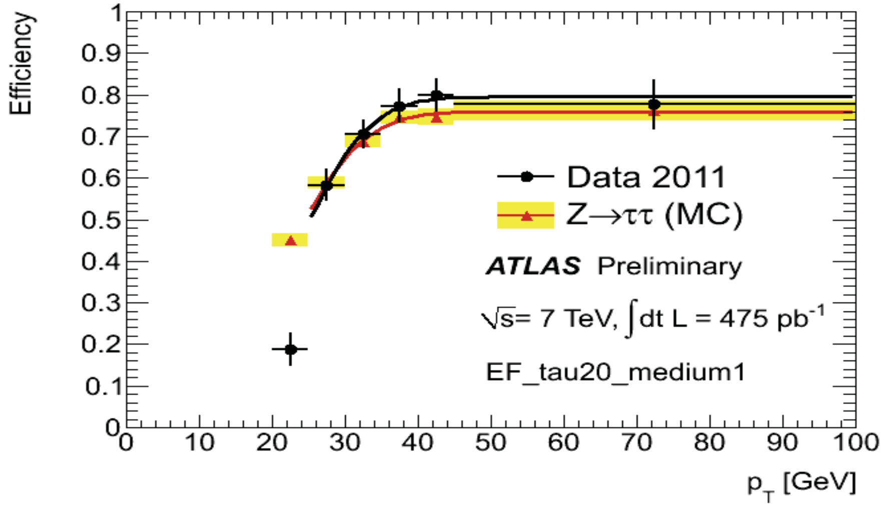


Trigger


Trigger eff.
ATLAS Preliminary
Data 2011 ∫ Ldt=206 pb-1
e20_medium trigger
L1 (ET>14 GeV)
L2 (ET>19 GeV)
EF (ET>20 GeV)
electron ET (GeV)

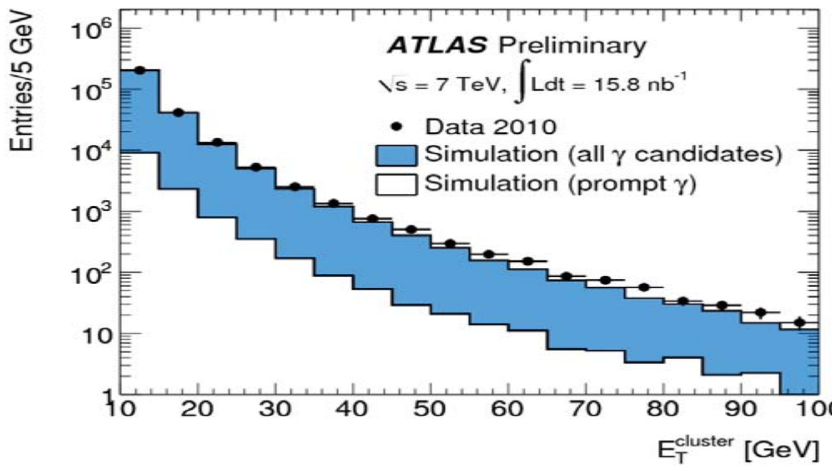

EF_mu18 Efficiency
ATLAS Preliminary
2011 Data ∫ L dt = 138 pb-1
DATA
MC
pT [GeV]

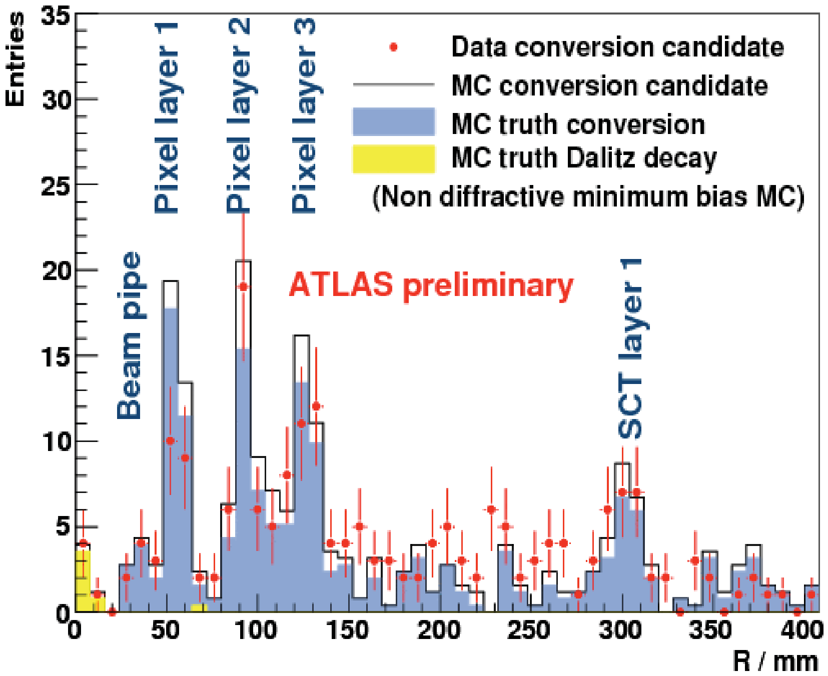

Efficiency
ATLAS Preliminary
Data 2011
∫ L dt ~209 pb-1
g20_loose efficiency
pT (GeV)

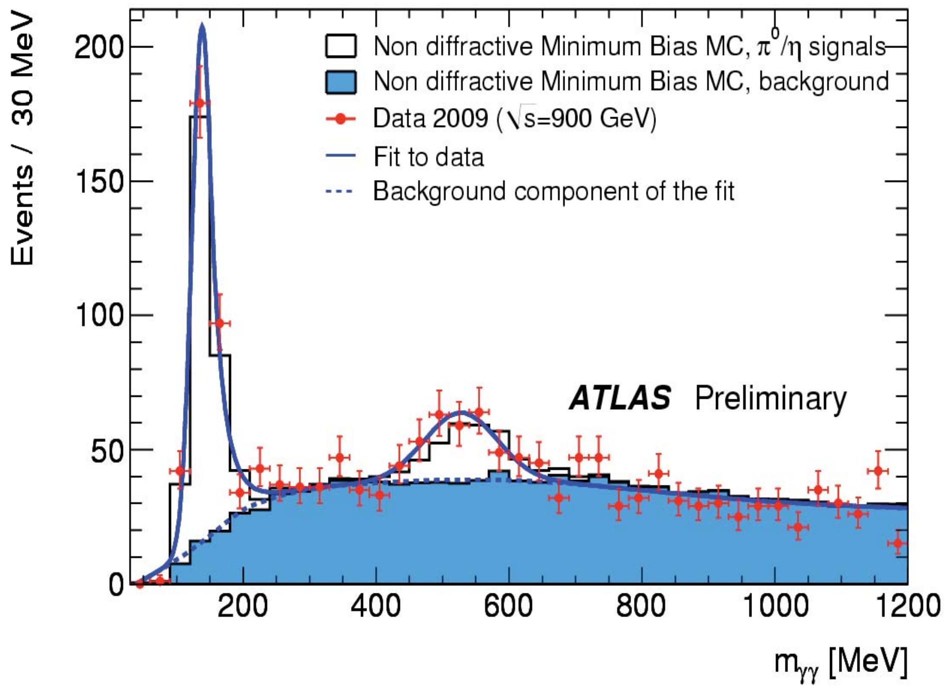

Efficiency
Data 2011
Z→ττ (MC)
ATLAS Preliminary
√s= 7 TeV, ∫dt L = 475 pb-1
EF_tau20_medium1
pT [GeV]

Electron/Photon Performance

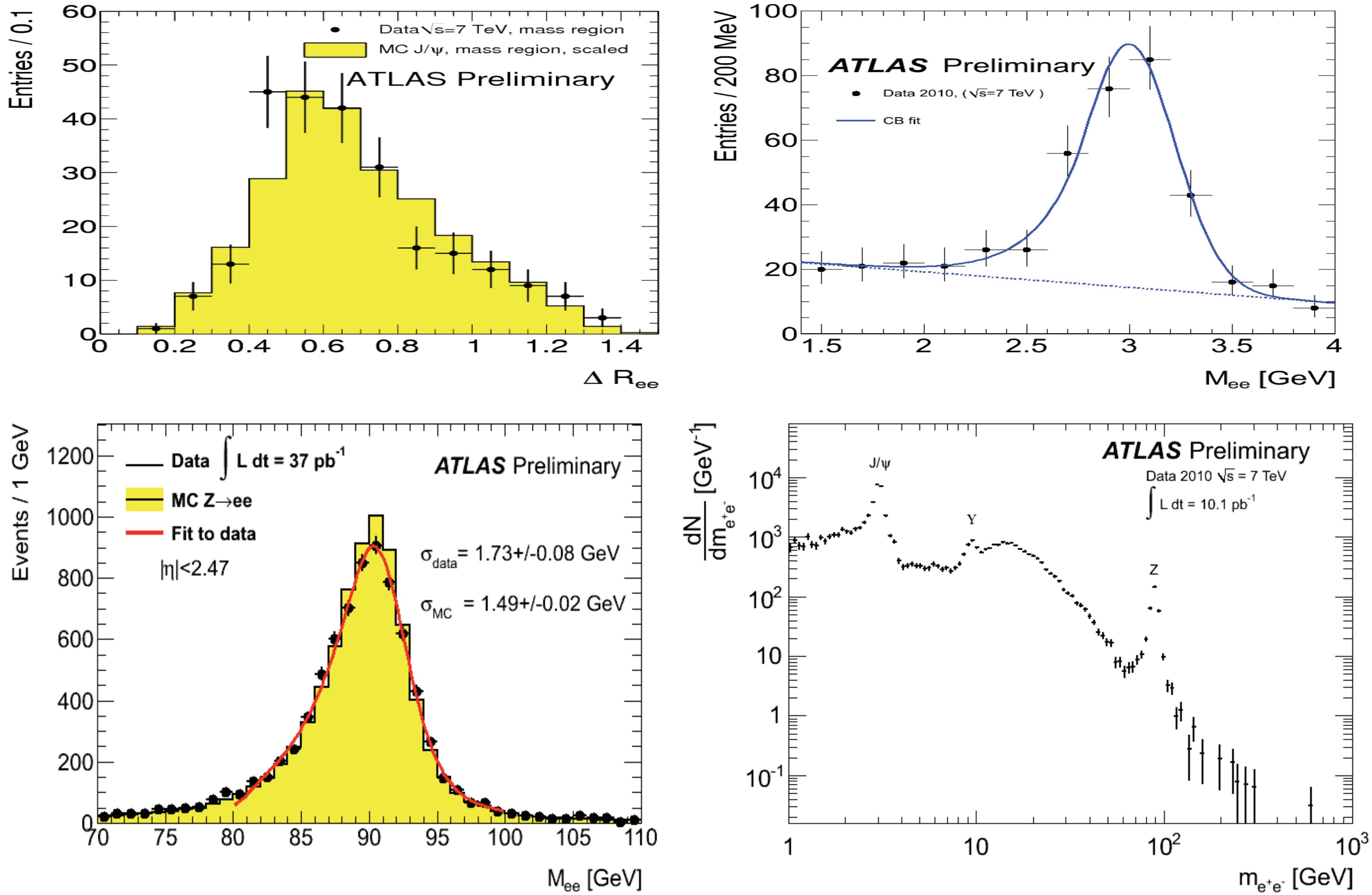
- Electrons: EM clusters matched to tracks
- Unconverted photons: EM clusters not matched to tracks
- Converted photons: EM clusters matched to track from conversion vertices or tracks consistent with





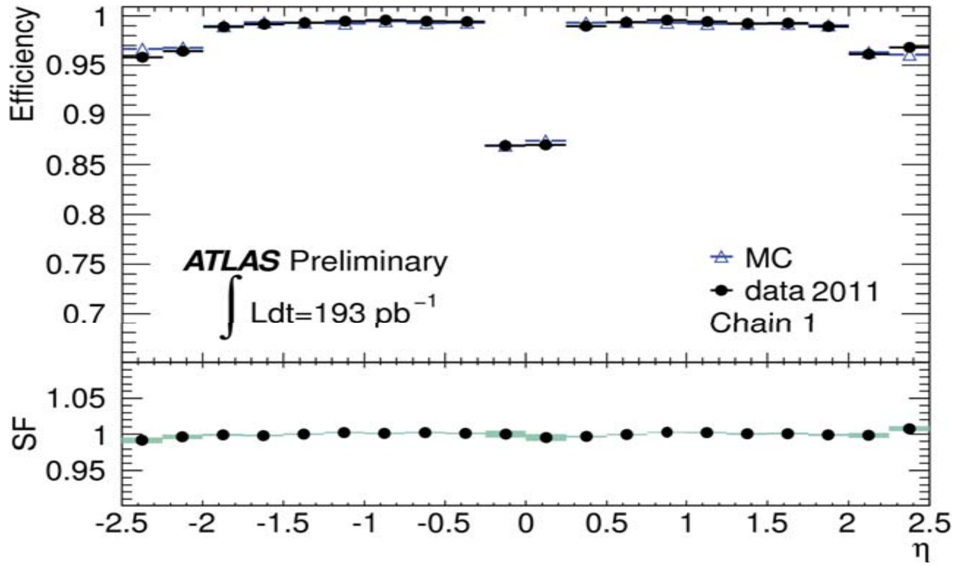


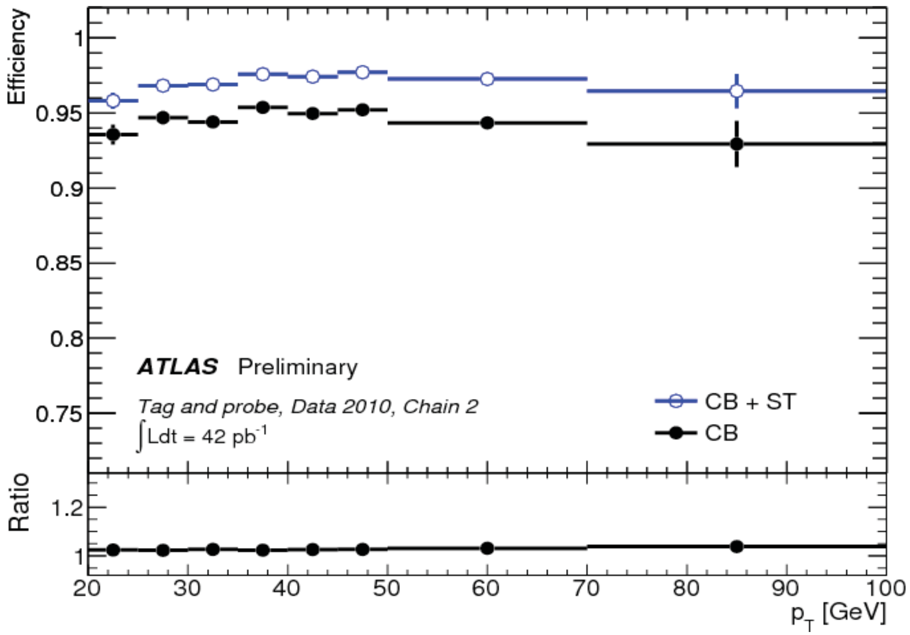
Electron/Photon Performance

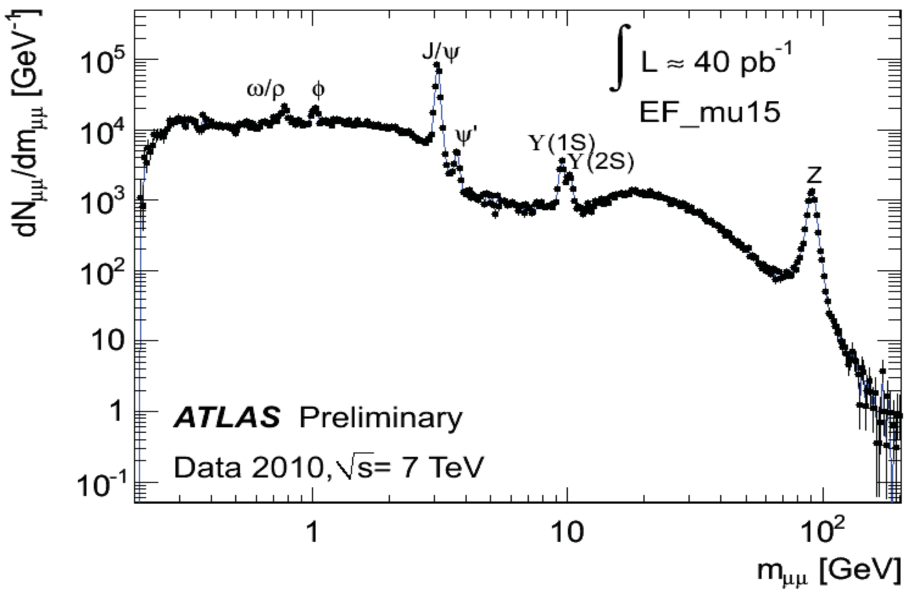


Muon Performance

- Muon reconstructed by matching muon spectrometer (MS) and inner detector (ID) tracks – combined (CB)
  - Statistical combination
  - Global refit of MS and ID hits
  - Segment Tagging (ST)

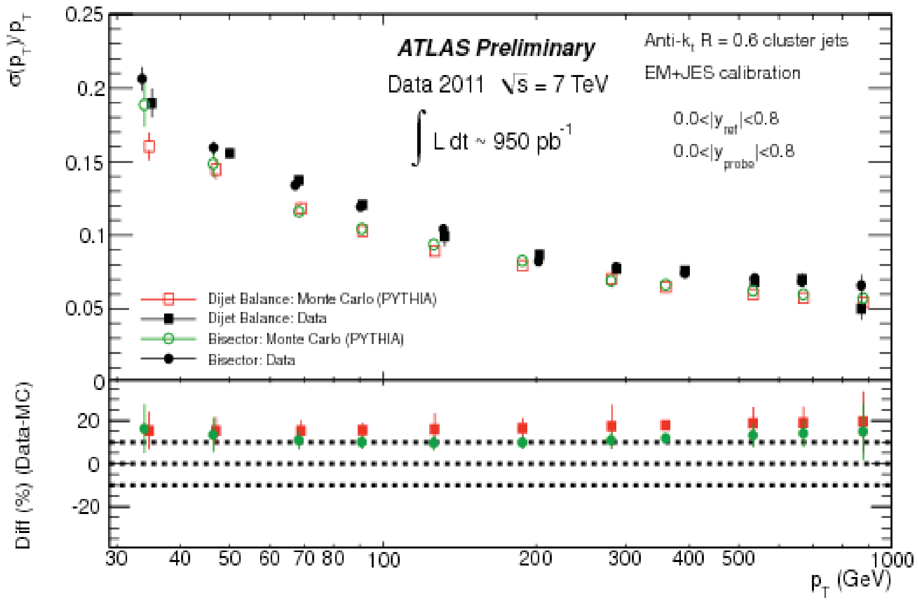


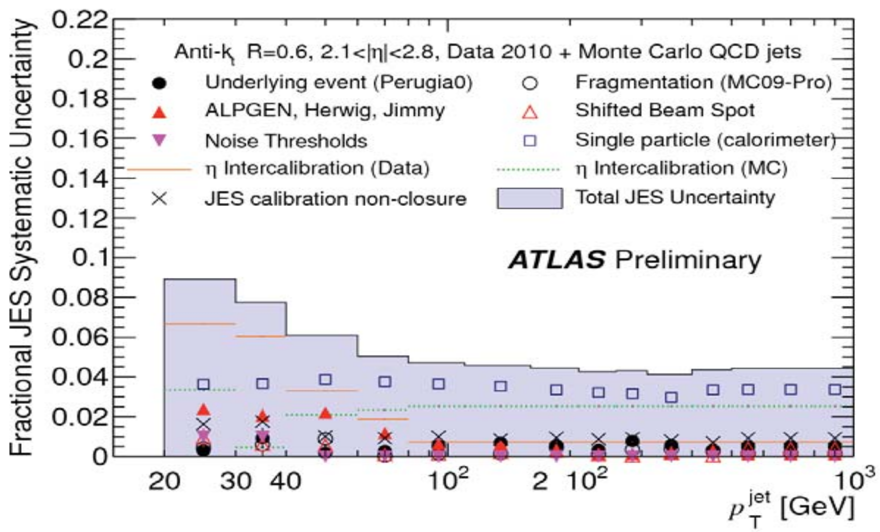


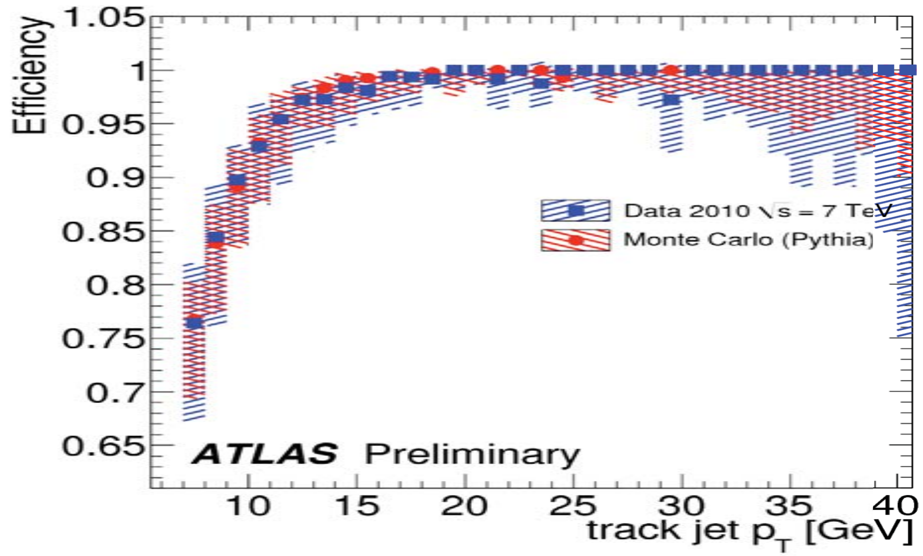


Jet Identification

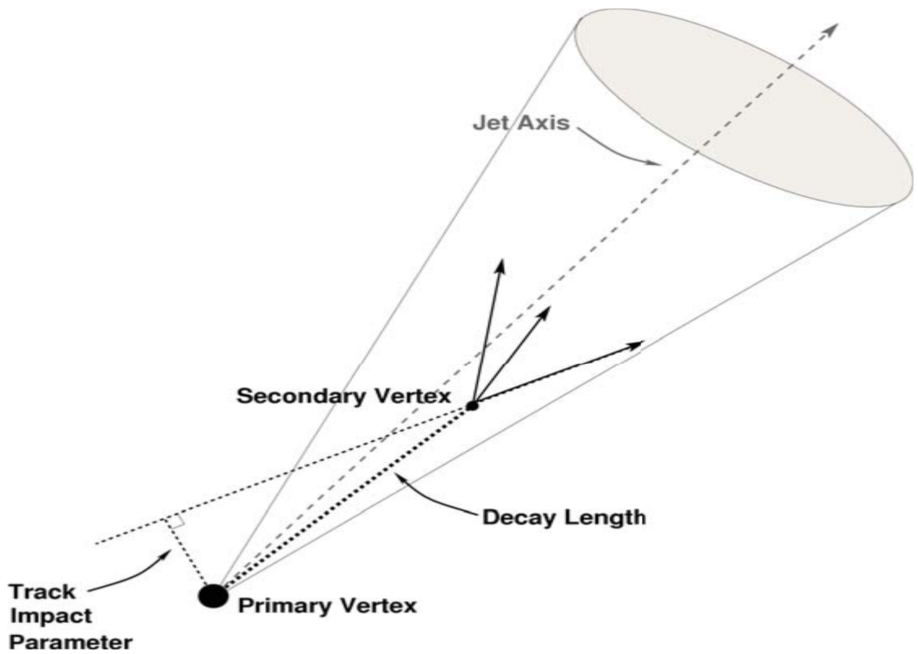
- With anti-k_T with R=0.6 using calorimeter topological clusters as input
- Calorimeter and track based jets
- Jet Energy Scale (JES) corrections based simulation and test beam
  - Systematics estimated using di-jet and γ-jet events
- Resolution measured using di-jet balance and bisector methods
- Efficiency measured with respect to track jets using a tag and probe method

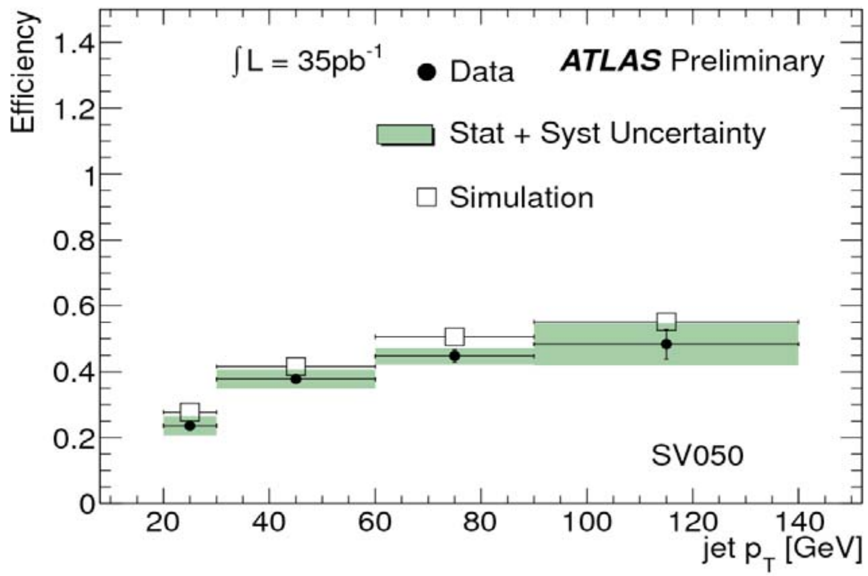


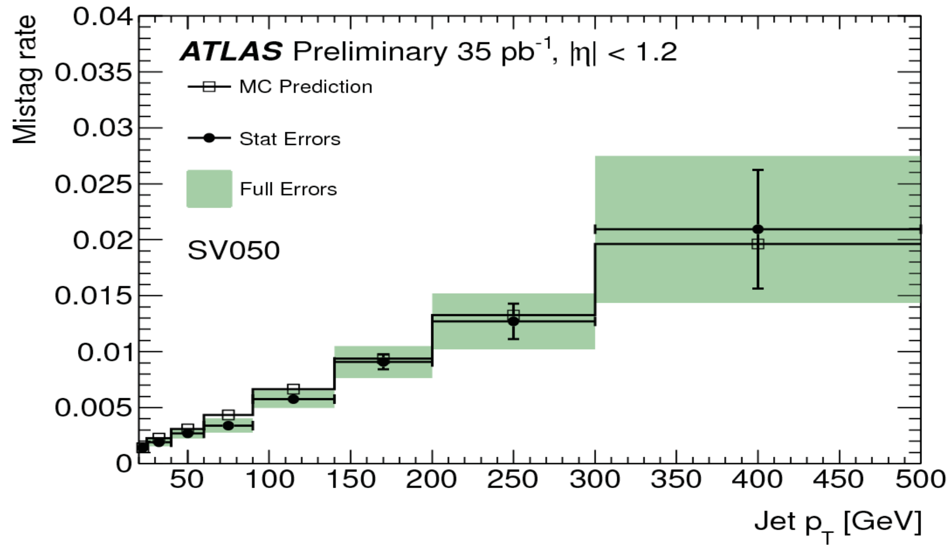




b-jet tagging Performance





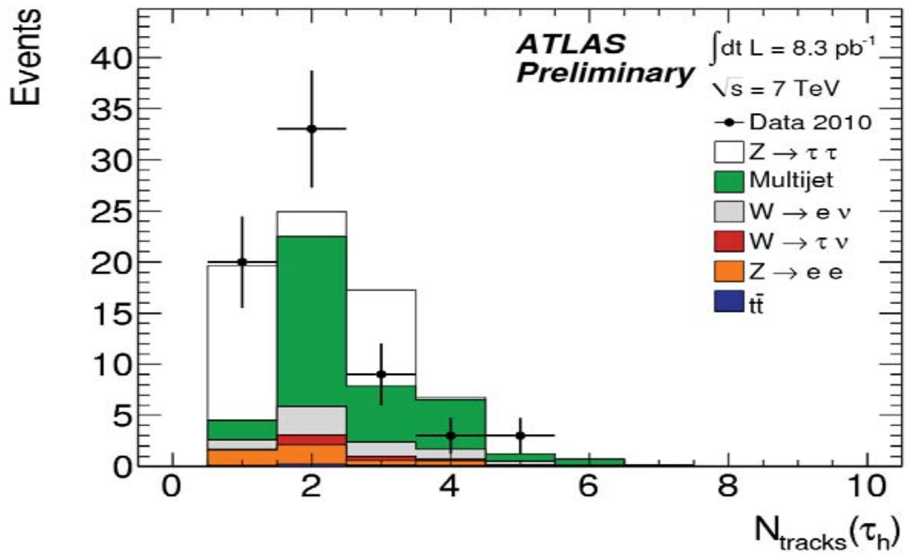


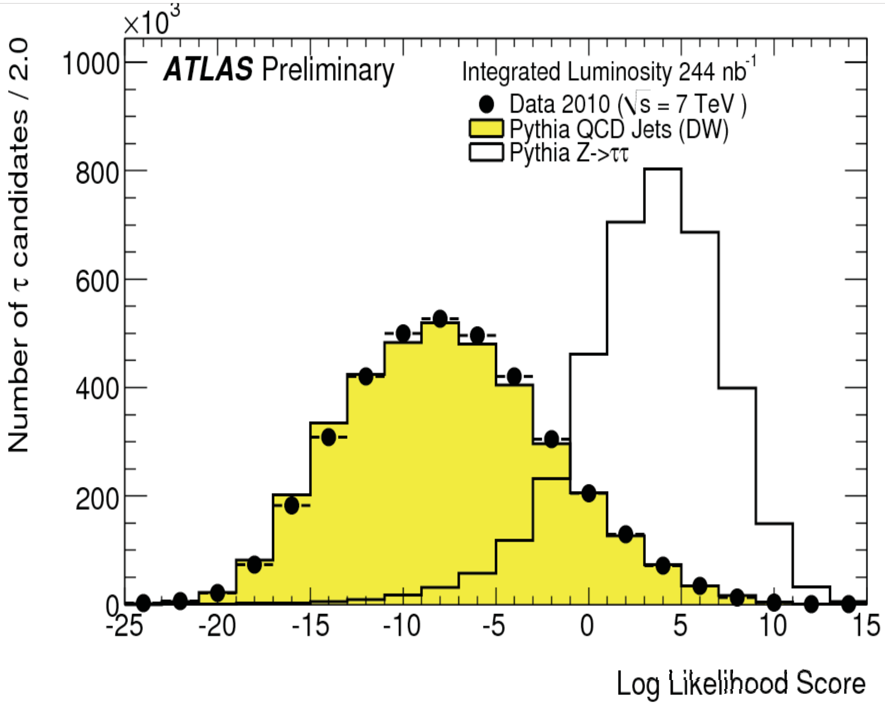
3 methods used in early data:

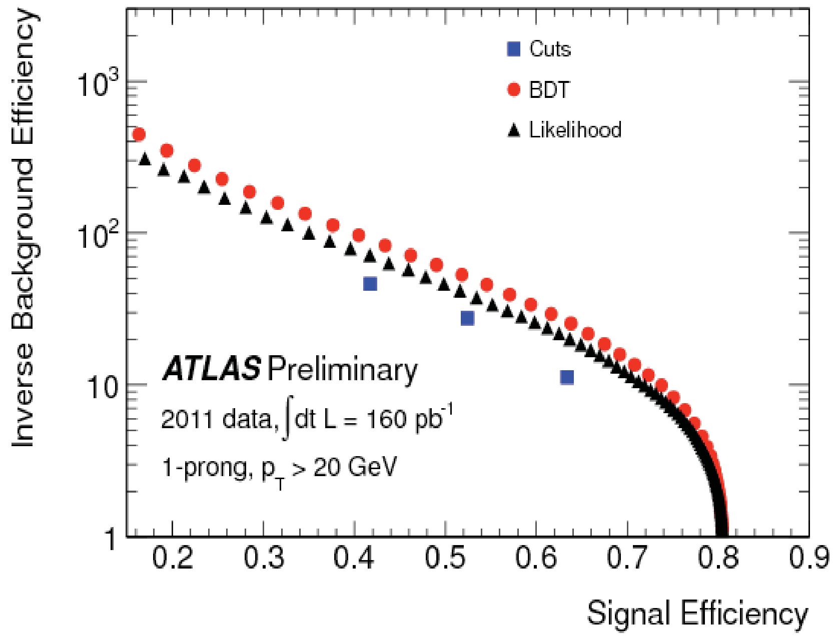
- SV0 – Signed decay length significance
- TrackCount – counting number of track with significant impact parameter
- JetProb – probability of all tracks originating from the primary vertex

Hadronic τ-jet Identification

- Hadronic τ-jet plays a key role in Higgs searches
- τ-jet identification: narrow calorimeter shower matched to 1 or 3 tracks

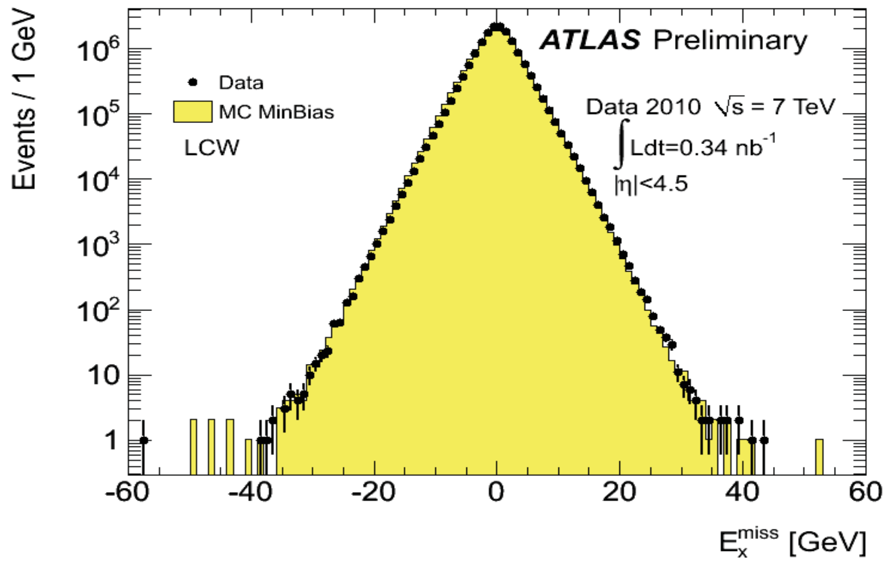


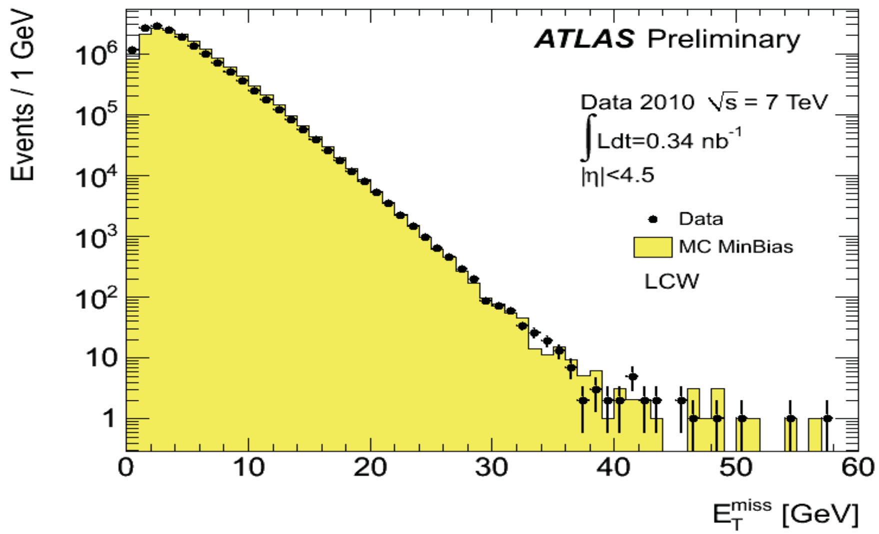


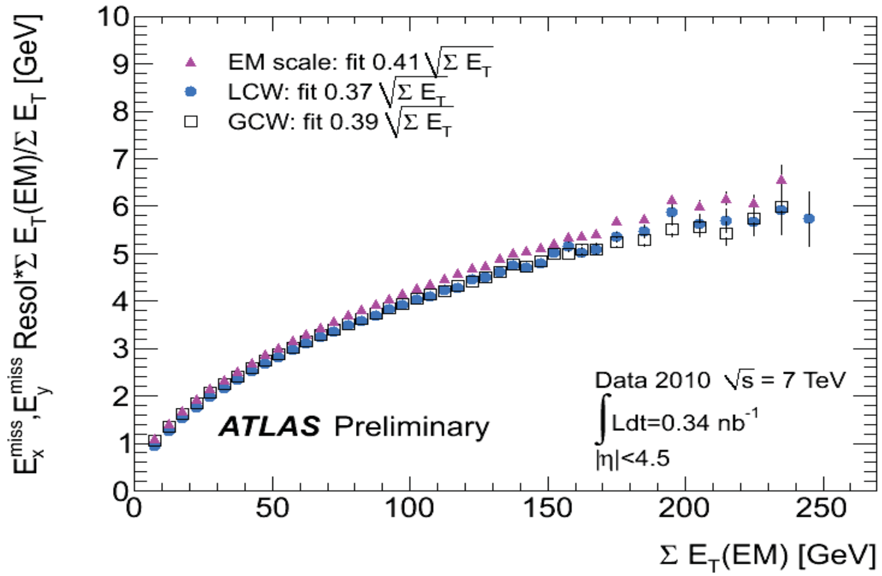


Missing E_T Performance

- Missing E_T needed for Higgs and new Physics searches
- Calibrated using a large sample of Minimum Bias events







Statistical combination procedure

- **The profile likelihood ratio is used as test statistics** $\lambda(\mu) = L_{s+b}(\mu, \hat{\hat{\nu}})/L_{s+b}(\hat{\mu}, \hat{\nu})$
- one-sided variants of the test statistic are used for upper-limits and discovery
- The distribution of the test statistic is obtained in two ways:
  – Ensemble tests with toy Monte Carlo using a fully frequentist procedure
  – Using asymptotic distribution of likelihood ratio (improved X^2 method)
- nuisance parameters are "profiled" based on the data
- Primary result based CLs, conservatism introduced to protect against downward fluctuations
  – Additional comparisons with Bayesian procedure with a uniform prior on μ