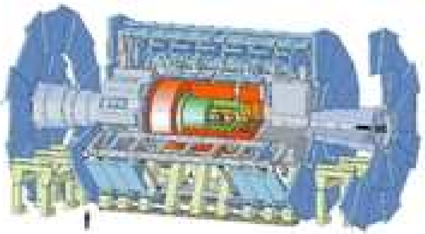
the ATLAS Experiment



Status of Higgs search in ATLAS

G. Chiodini – INFN Lecce

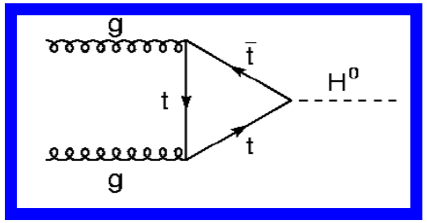
On behalf of ATLAS collaboration

Interpreting LHC Discoveries —— Workshop Oct 31 - 25 Nov 2011

Outlook

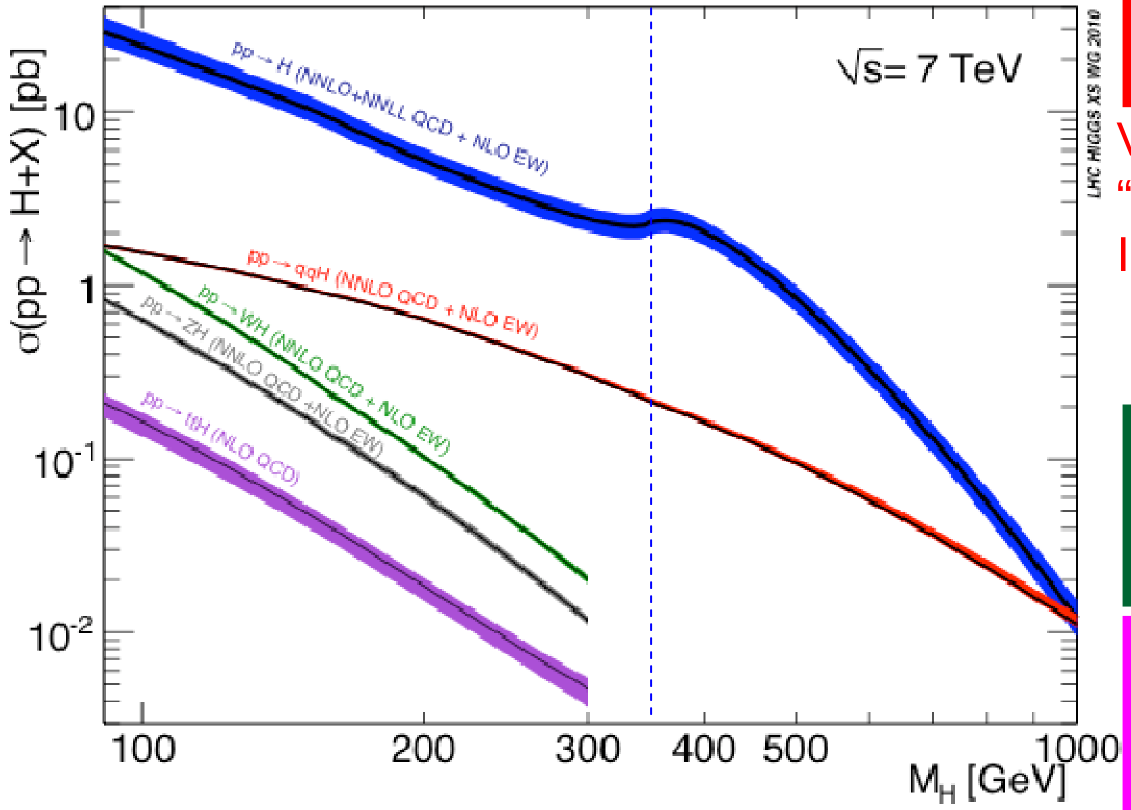
- Higgs cross-sections, branching ratio and background
- ATLAS detector and data taking in 2011
- Higgs searches status
  - Analysis strategy
  - Intermediate and high mass channels (highest sensitivity)
  - Low mass channels (low sensitivity but favorite by EW fit)
  - Combined channels
  - Prospective
- Conclusions

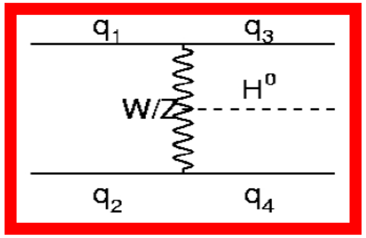
Higgs cross-sections



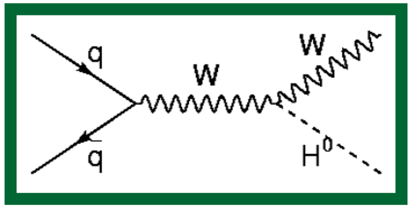
Gluon Fusion is dominant (x10 Tevatron)

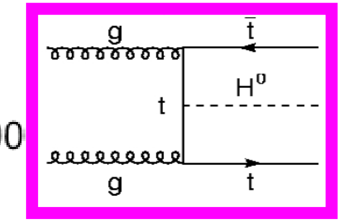
ttbar thr.





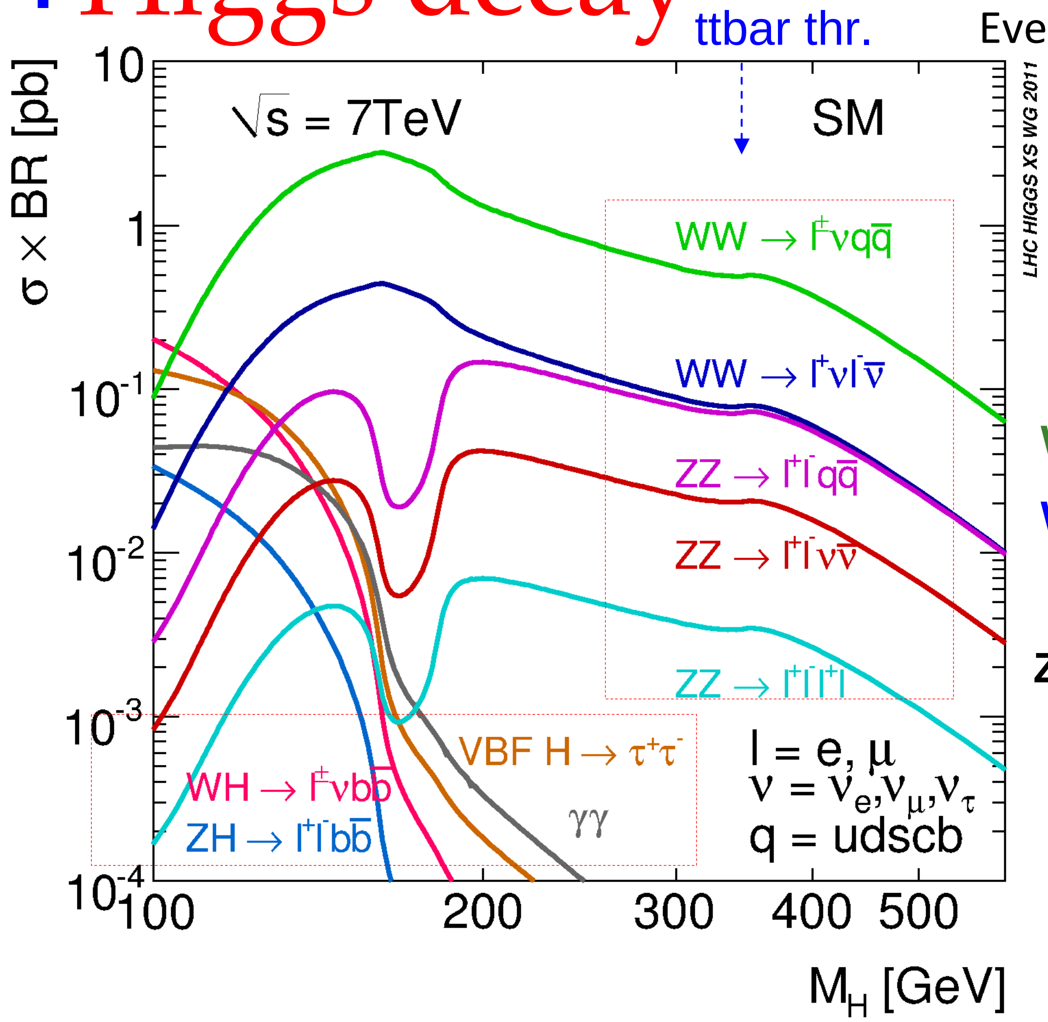
Vector Boson Fusion is very "distinctive" (2 forward jets). Increasing importance in the future.





Associated production (easy trigger and signature). Important for low mass

Higgs decay



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

$WW^{(*)}\rightarrow l\nu 2q$ most copious

$WW^{(*)}\rightarrow l\nu l\nu$ most sensitive at intermediate mass

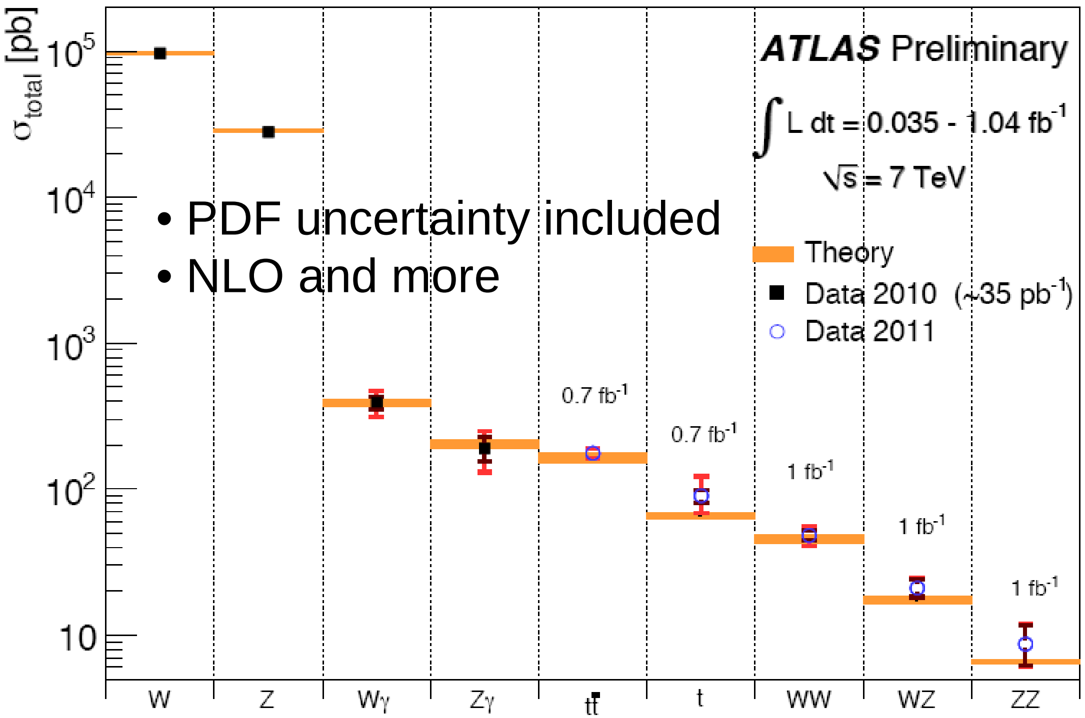
$ZZ^{(*)}\rightarrow$ llqq(bb), llνν, llll high mass

H→ γγ, ττ rare but good S/B at low mass

W/Z+H→bb good for discovery at low mass and measure SM properties

EW and QCD background

LHC vs Tevatron



SM predictable over 4 order of magnitude at the highest energy

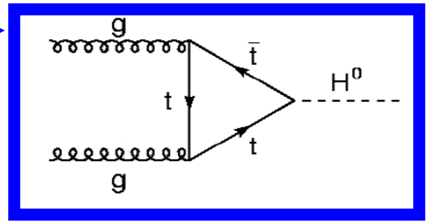
S/B better for M_H>140GeV

- Large increase gluon-fusion
- Slow increase irriducibile di-boson

S/B worse M_H<130 GeV

- Low increase of ass. prod.
- Large increase of ttbar and Z/W+b-jets (to be precisely measured)

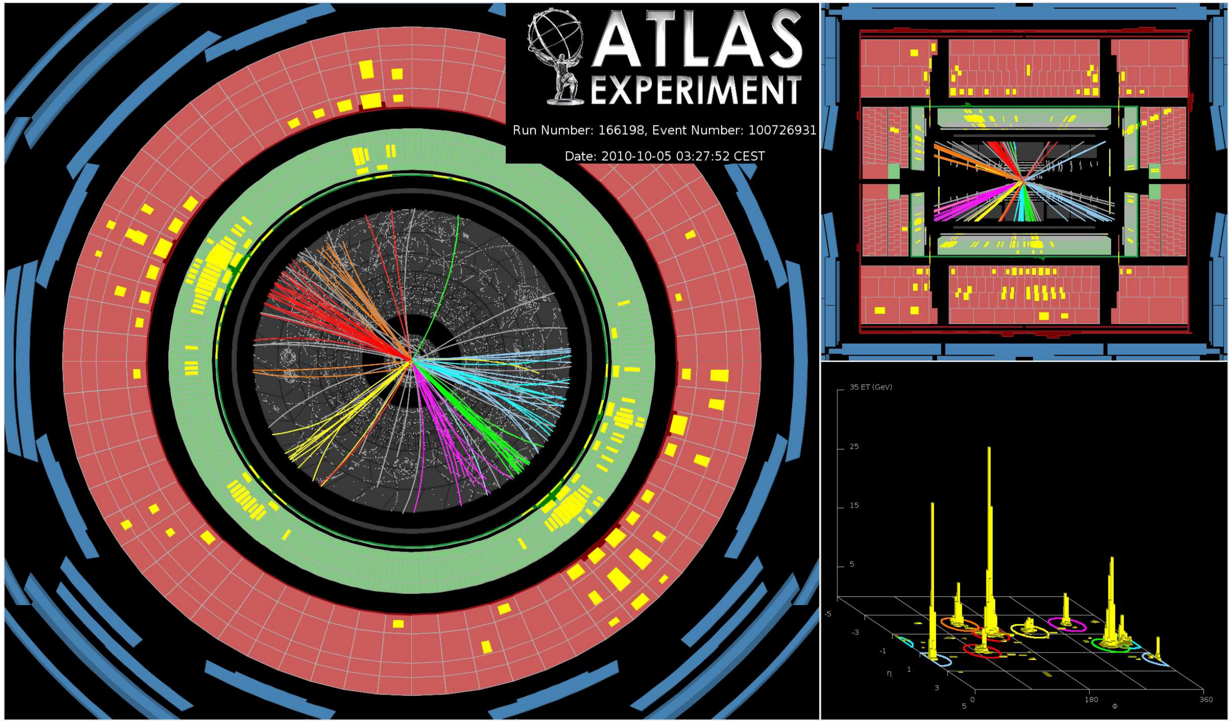
M_H=130GeV



QCD BG:

- Di-jet cross-section = 10^{10} pb for P_T>8 GeV (vs few pb Higgs cross-section)
- Multi jets background estimate from data and MC turn out negligible after cuts

Fighting QCD multi-jet background



8 jets events:

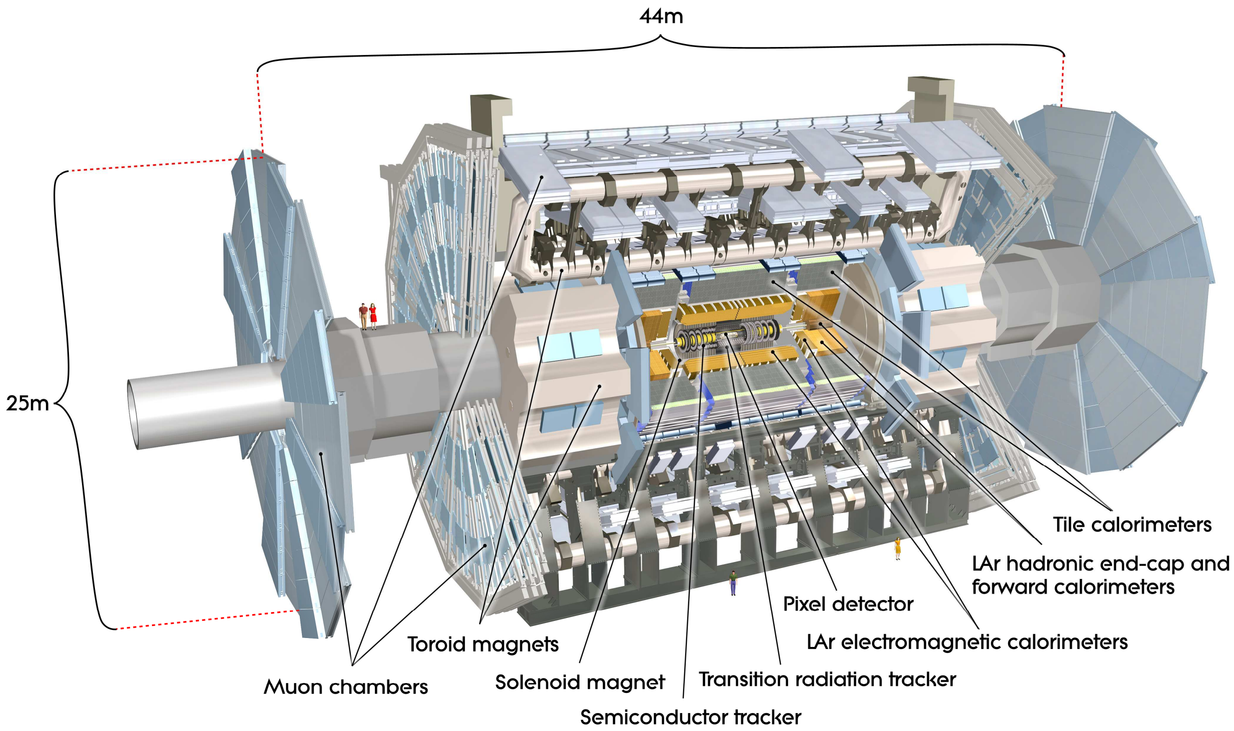
- leading jet: pT = 290 GeV, η = -0.9, φ = 2.7
- sub-leading jet: pT = 220 GeV, η = 0.3, φ = -0.7
- Missing ET = 21 GeV, φ = -1.9
- Sum ET = 890 GeV

Jets can fake :

- leptons from Heavy Flavor decay $\rightarrow$ Isolation
- E_T^{miss} from mis-measure $\rightarrow$ $\Delta\phi$(MET,leading jet)>0.3
- γ's $\rightarrow$ Isolation and π_o rejection

Cuts not explicitly mentioned here

ATLAS detector



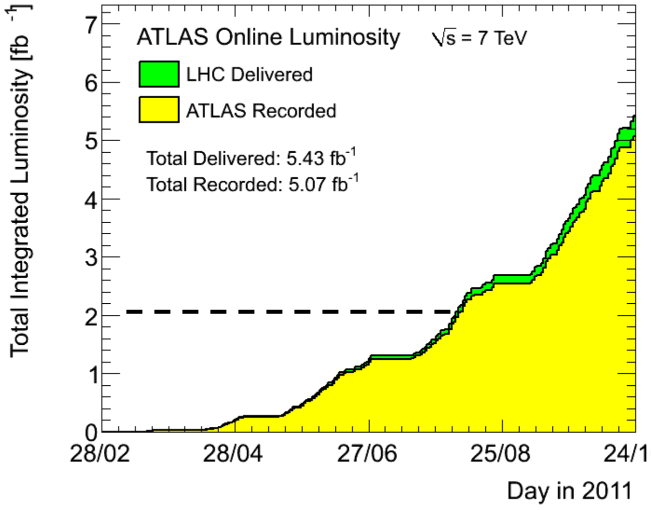
Three trigger levels
- **L1: hardware selection of Regions of Interest**
- **L2: software L1 confirm with all systems**
- **L3: offline-like reconstruction**

Inner detector (|η|<2.5)
- **2T solenoid**
- Vertexing and b-tag: **Si Pixels**
- Tracking: **Si Strip + Straw tubes** (with e/h separation)

Sampling calorimeters (|η|<5)
- **EM: accordion Pb/LAr**
- **HCAL: Transverse Fe-Sci**
- **FCAL: road-tube W-Cu/LAr**

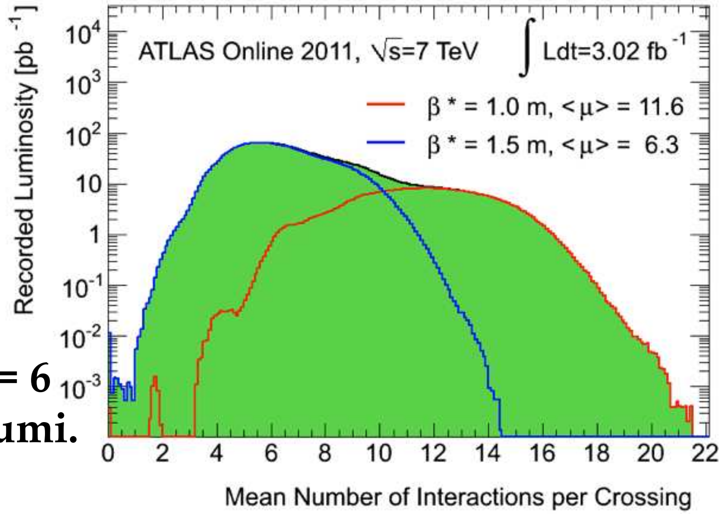
Muon System (|η|<2.7)
- **Standalone**
- **3 large air core toroids**
- **Gas detectors:**
  - **-Precision Chamber: MDT/CSC**
  - **-Trigger and 2nd view: RPC/TGC**

ATLAS in data taking in 2011



Results presented for $L<2fb^{-1}$ and $\beta^*=1.5$ m

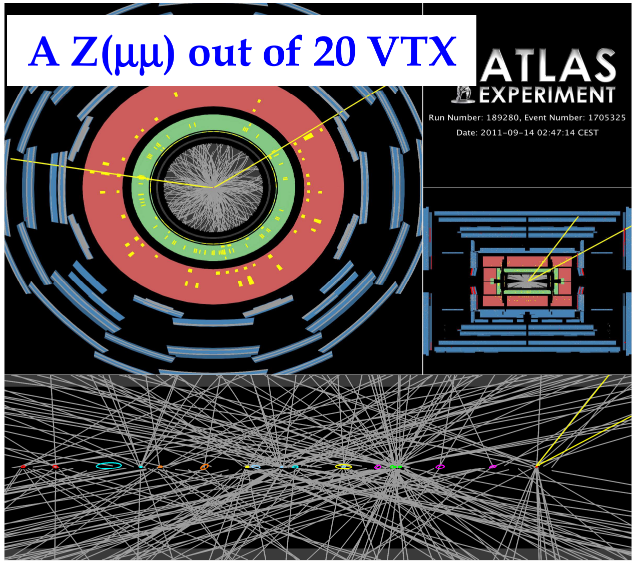
<Int/Bunch>= 6 weighted by lumi.



Data take efficiency 95%
Green Flag Data Quality all sub systems 90-100%

Instantaneous luminosity reach $3.5\times10^{33}cm^{2}s^{-1}$
50 ns bunch trains for ~all 2011 data

High pile-up in and out of time affect:
- Trigger efficiency
- Resolution, energy scale, isolation …



Detector performance and simulation

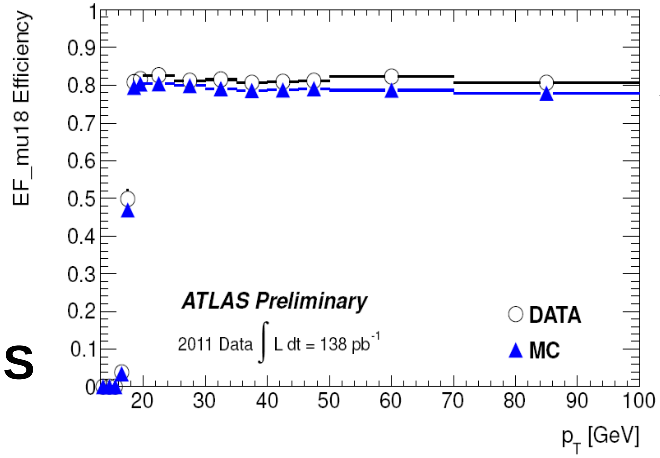
Higgs search requires excellent performance:

- physics object reconstruction:
  - ✓ muon, electron, photon, jet
  - ✓ tau
  - ✓ missing transverse energy (MET)
  - ✓ b quark jet tagging (b-tag)
- reconstruction and understanding of rate:
  - ✓ W/Z
  - ✓ W/Z + jets , W/Z + b-jets
  - ✓ ttbar, single t
  - ✓ di-boson

ENTIRE DETECTOR MUST WORK AND BE WELL SIMULATED

Trigger

Single μ trigger turn-on curve

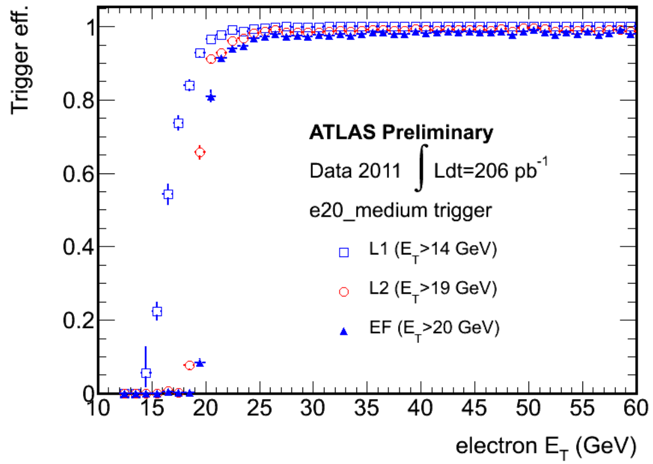


MS

due to coverage

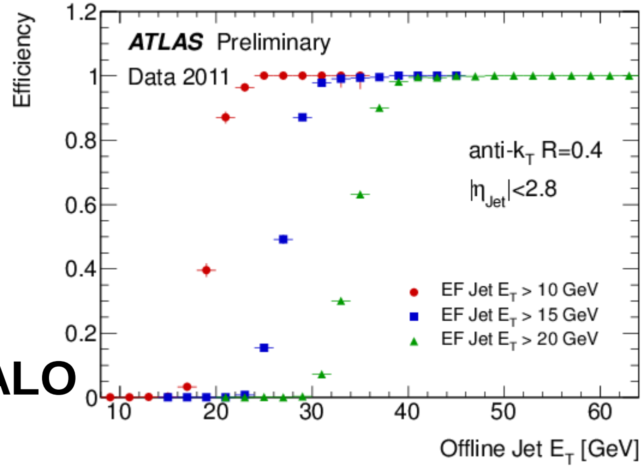
Very low and sharp μ threshold

Single e trigger turn-on curve



ECAL

Single jet trigger turn-on curve



CALO

Lepton triggers the most efficient and clean

Higgs searched based on single lepton trigger except for:
- $H \rightarrow \gamma\gamma$ di-photon trigger
- $H \rightarrow \tau_{had}\tau_{had}$ dedicated hadronic τ trigger

QCD BG and trigger kill pure jet channels
- H→cc, bb, gg, V(2q)V(2q)

Higgs search strategy

"Cut-and-Count" or (unbinned) binned Log Likelihood analysis.
Other MultiVariateAnalysis (MVA) in progress

- Signal selection
  - **Trigger**
    - single and di-lepton, single and di-photon with
    - THRESHOLDS changed in time with increasing luminosity
  - Green data quality flag
  - Select collision events
  - Select **final state** physics objects
  - **Cuts**
  - **Acceptance**
- Background evaluation
  - MC (well measured or very rare EW processes).
  - Data Driven (QCD backgrounds such as multijets and V+jets)
    - Measure "enhanced BG" in control region (defined by removed or reversed cuts)
    - Extrapolate "enhanced BG" to signal region by MC or data shape.
    - Validate with MC
- Trigger and reconstruction efficiency from Tag&Probe method using JPSI and Z

Intermediate and high mass search with WW

- $H \rightarrow WW^{(*)} \rightarrow l\nu l\nu$ (highest sensitivity)
- $H \rightarrow WW^{(*)} \rightarrow l\nu qq$

$H \to WW^{(*)} \to l\nu l\nu$

Most sensitive process for $130 < m_H < 200$ GeV but challenging because reconstruction of the invariant mass not possible due to the two neutrinos.

Selection:

- High P_T opposite sign leptons. **3 channels: ee, μμ, eμ**
- Large $E_{Tmiss,rel}$

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

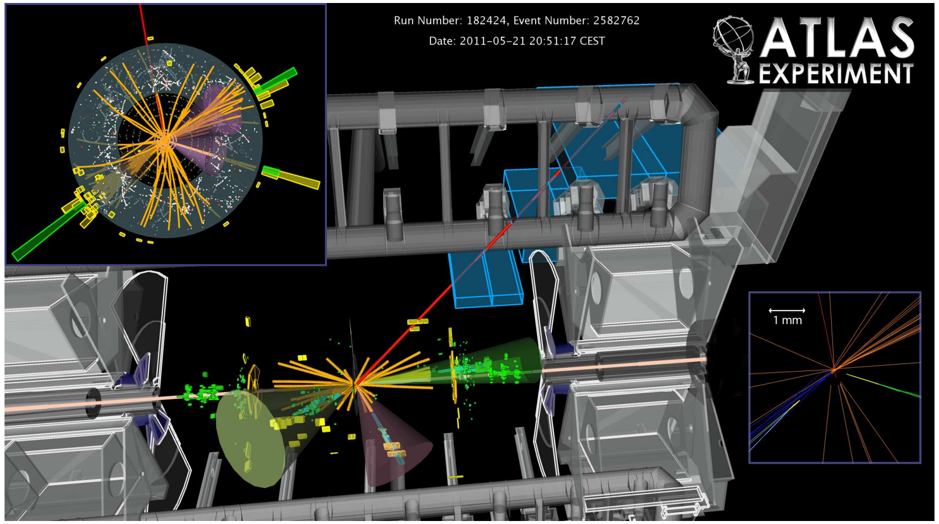
- Topological cuts on di-lepton ($M, P_T, \Delta\phi$)
- Cut on transverse mass $0.75 \mathrm{x} M_H < M_T < M_H$

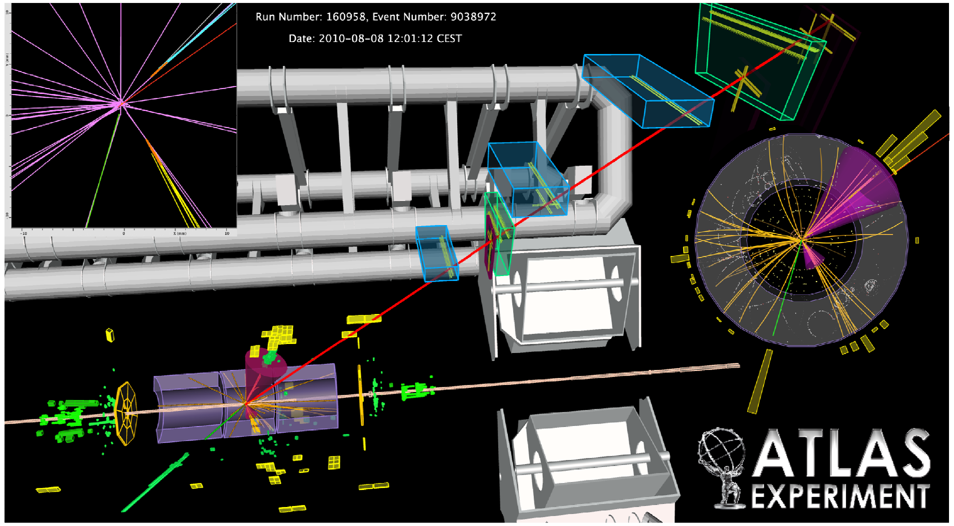
$$m_{\mathrm{T}} = \sqrt{(E_{\mathrm{T}}^{\ell\ell} + E_{\mathrm{T}}^{\mathrm{miss}})^2 - (\mathbf{P}_{\mathrm{T}}^{\ell\ell} + \mathbf{P}_{\mathrm{T}}^{\mathrm{miss}})^2}$$

Background:

Irriducible **WW**. For one additional jet: **Drell-Yan** and **ttbar**.

Fighting ttbar→WbWb BG





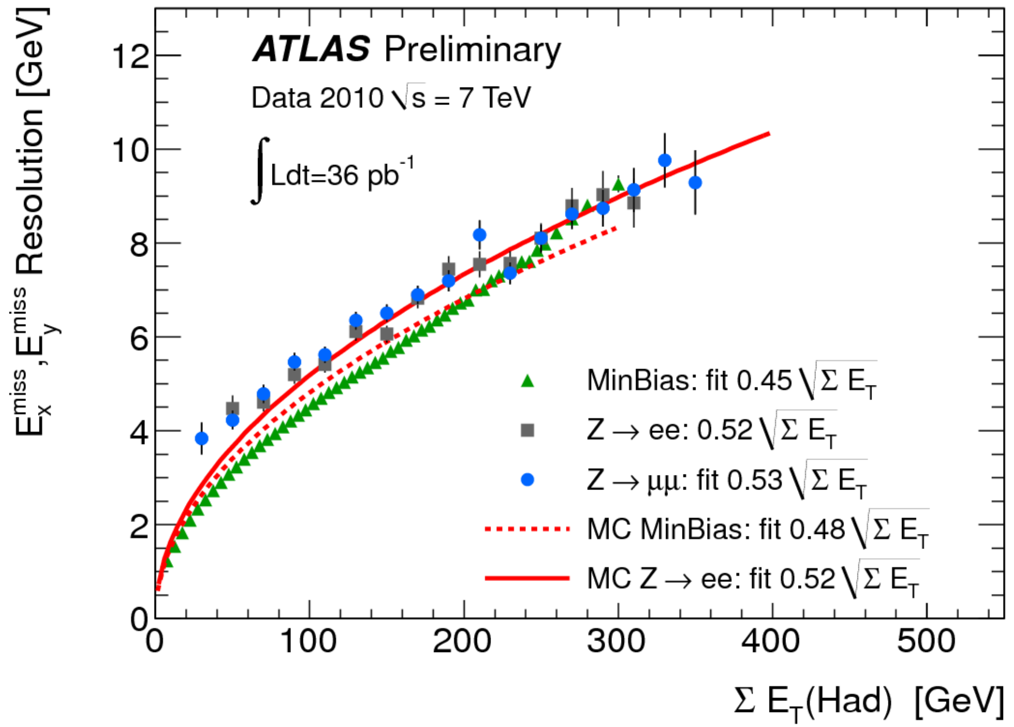
- Veto on b-jets or jets multiplicity
- Veto on leptons multiplicity
- Use MET cuts

Cuts not explicitly mentioned here

Missing E_T resolution

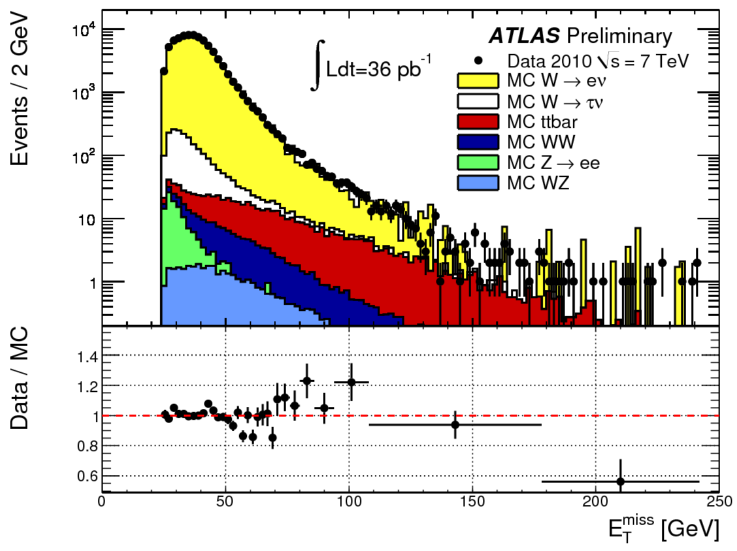
MET = Negative vectorial sum ET clusters and selected μ's (clusters due to μ 's removed)

resolution (GeV) ~ 0.5/sqrt(sum all E_T)

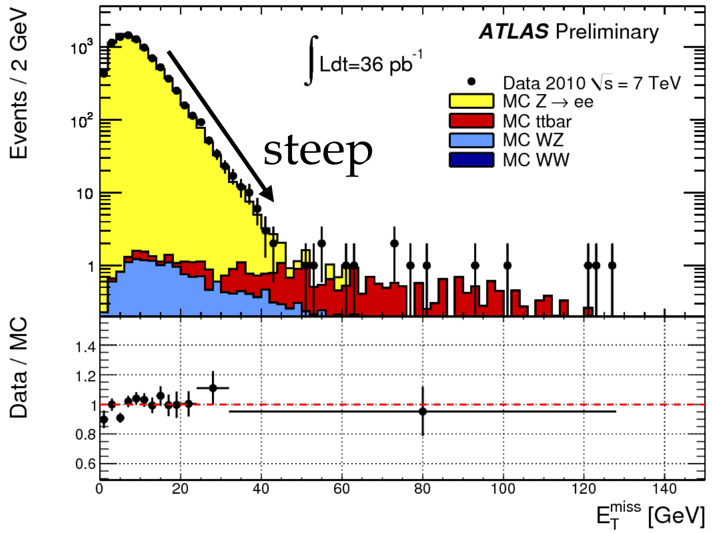


MET calibrated with a large sample of minimum bias events

MET in W→eν events

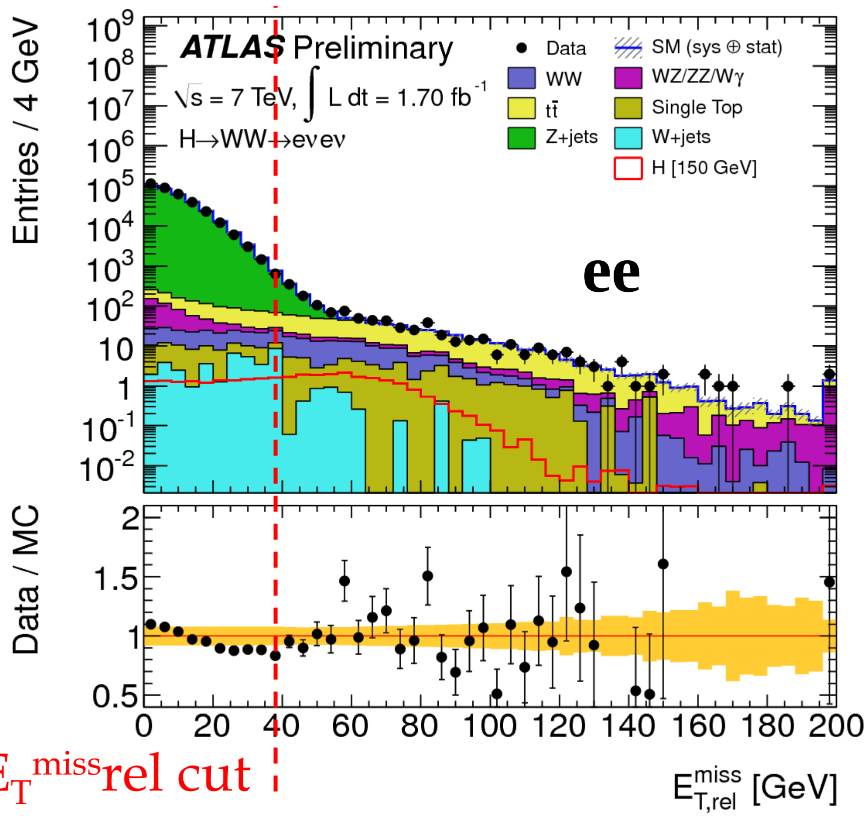


MET in Z→ee events

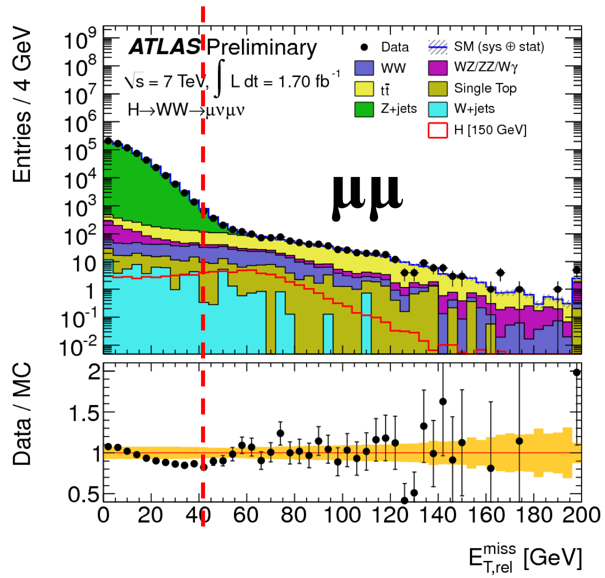


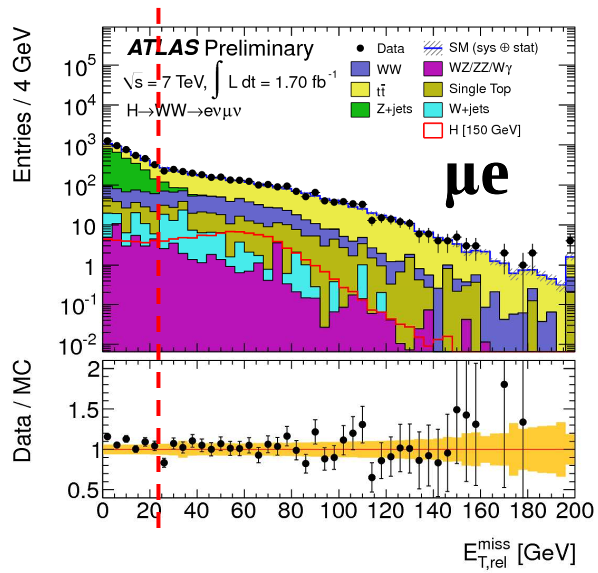
$H \rightarrow WW^{(*)} \rightarrow l\nu l\nu$ E_T^{miss}

E_T^{miss}rel distribution after lepton P_T cuts



E_T^{miss}rel cut



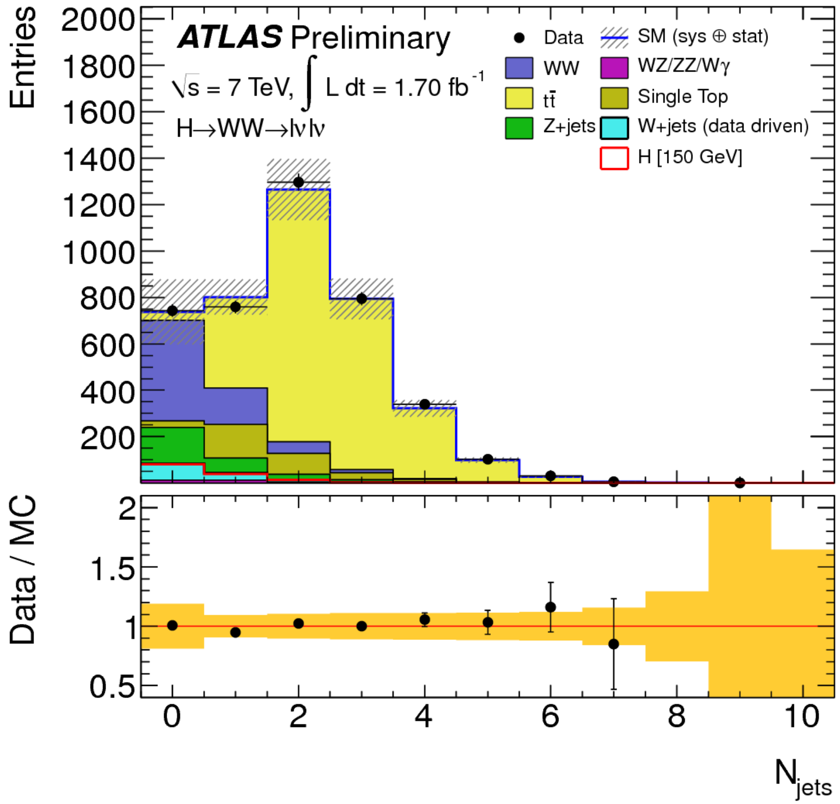


A large missing energy from neutrinos is essential to remove QCD+Z/W+jets BG.

H→ WW(*)→lνlν Phase Space Slicing

Njets samples have different degrees of purity:

- No jets bin is the most pure
- Optimization of Njets samples independently increase the sensitivity



Divide data in two disjoint samples after $E_{Tmiss,rel}$ cut:

- No jets bin
- One jet only bin: $P_T > 25$ GeV, $|\eta| < 4.5$ GeV
- No VBF yet (two jets bin)

$H \rightarrow WW^{(*)} \rightarrow l\nu l\nu$ Background

Background estimate from data in counting experiment is essential

- The two largest backgrounds (WW and top) estimate from data:
  - Control regions in data rich in WW or top backgrounds
  - Extrapolate this measurement to data signal regions using MC shapes and normalization

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

Control regions:
- Inverted topological cuts
- Inverted veto ttbar cuts
- Leptons looser or anti-identification

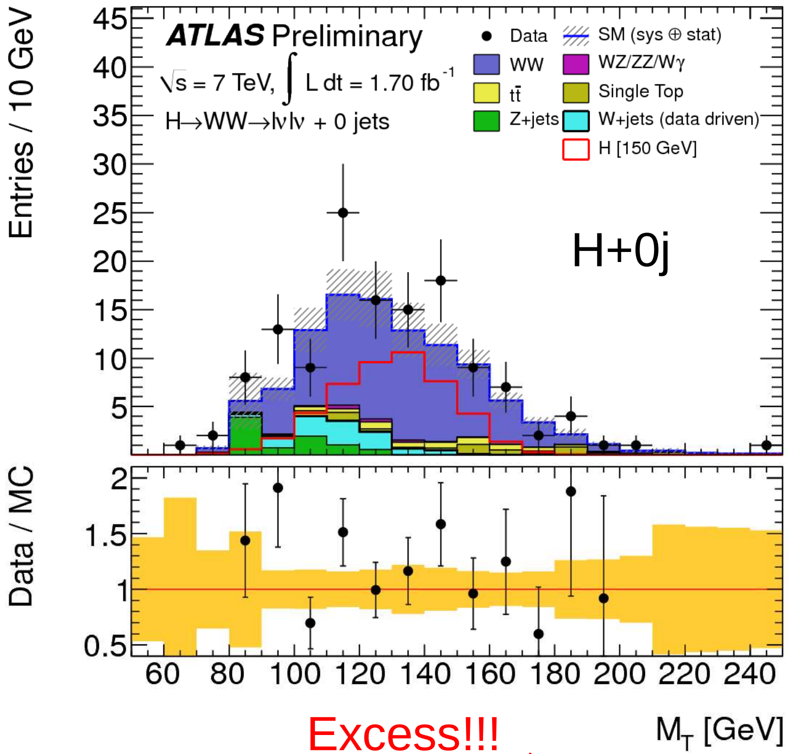
Validated with MC

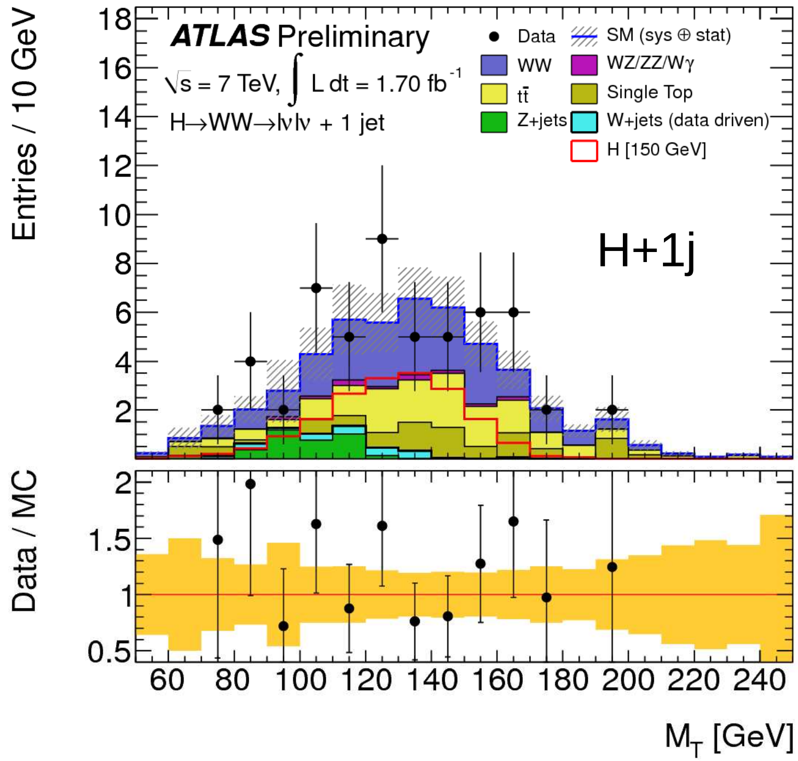
Control Region	MC expectation	Observed
WW 0-jet	250±50	237
WW 1-jet	139±18	144
Top 1-jet	350±100	316

- W+ jets entirely determined from data

- Remaining small backgrounds are taken from MC
  - Apply scale factor to Drell-Yan for potential E_T^{miss} mis-modelling

$H \rightarrow WW^{(*)} \rightarrow l\nu l\nu$ Event Yield vs M_T





Excess!!!

	WW	ttbar	Tot BG	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 for cuts optimized to select M_H=150 GeV Higgs decay.

Statistical test

Likelihood fit to the data in one or more variable
for each M_H hypothesis.

Test statistics is the **Profile Likelihood Ratio** $\mathbf{q_\mu = -2\ln[L(data|\mu s+b_\mu)/L(data|\underline{\mu}s+\underline{b})]}$

- Test signal strength $\mu=\sigma/\sigma_{SM}$
- s=signal. b_μ is the MLE of the BG given μ
- $\underline{\mu}$ and $\underline{b}$ maximize the likelihood with $0 <= \underline{\mu} <= \mu$

Exclusion limits: modified frequentist confidence interval = $1-CL_s$

- $\mathbf{CL_s=CL_{b+s}/CL_b}$ (protect against downward background fluctuations)
  Confidence Intervals:
  - $\mathbf{CL_{s+b} = P(q_\mu > q^{data}|\mu s+b_\mu)}$ where s+b=expected signal+background
  - $\mathbf{CL_b = P(q_\mu > q^{data}|0s+b_0)}$ background only hypothesis

Significance of an excess of events and **p-value** based on the statistical variable

- $\mathbf{Z=sqrt(q_0^{obs})}$ **(=0 for $\underline{\mu}$<0)** (1dof chi2-like distribution)

$H \to WW^{(*)} \to l\nu l\nu$ Exclusion limits

Upper limit on $\mu=\sigma/\sigma_{SM}$ at 95% CL based on CL_s

Observed is the measured limit. **Expected** is the median limit obtained with:

- MC pseudo-experiments with non signal
- Likelihood asymptotic formula

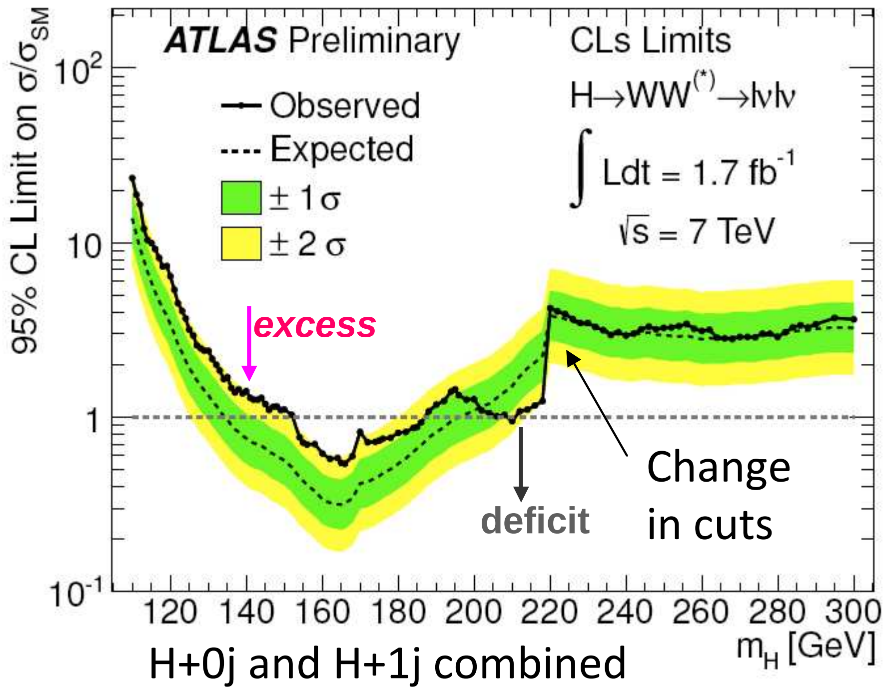
Obs. > Exp. → data "over fluctuate" . Obs. < Exp. → data "under fluctuate"

Obs. < 1 → SM Higgs excluded at more than 95% CL

SM Higgs boson with $154<m_H<186$ GeV is excluded at 95% CL

Expected exclusion mass range is larger $135<m_H<196$ GeV

The observed limit is within 2σ the expected one in the mass range 130 – 150 GeV (poor consistency with pure BG hypothesis)



H+0j and H+1j combined

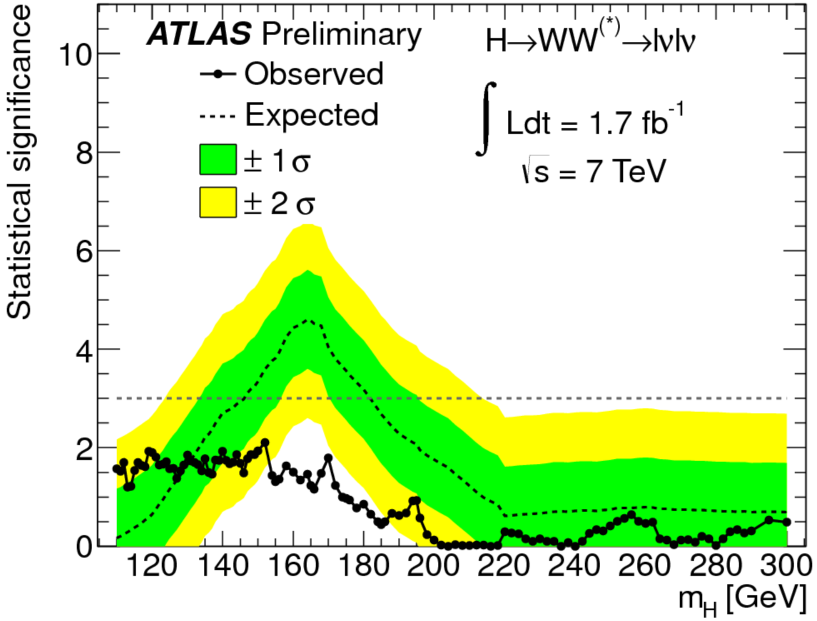
$H \to WW^{(*)} \to l\nu l\nu$ Event excess

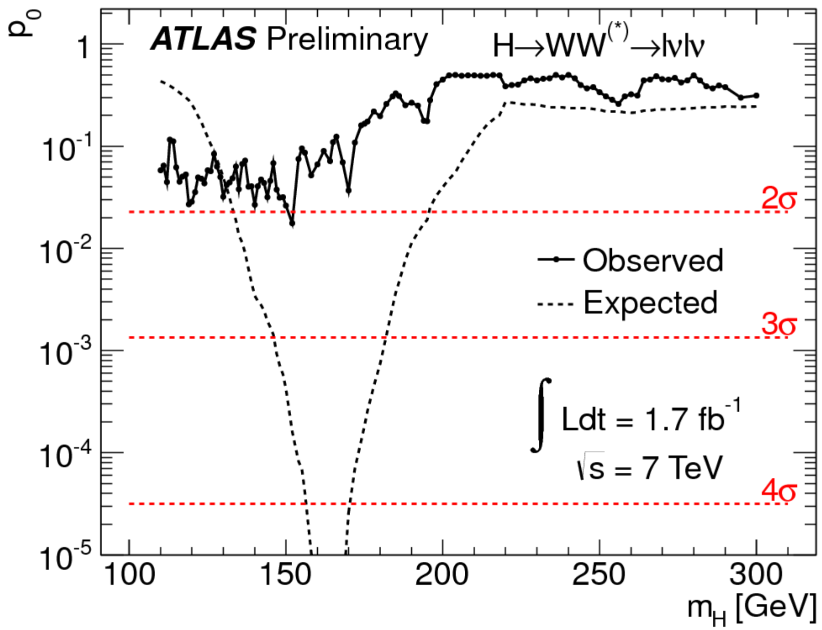
Statistical significance of the Higgs signal as a function of the mass

p-value Probability of upward background fluctuation above the observed significance (excess in data)

Z=sqrt(-2ln[L(data | b_0)/L(data | $\underline{\mu}$s+$\underline{b}$)])

P-value=[1 –erf(Z/sqrt(2))]



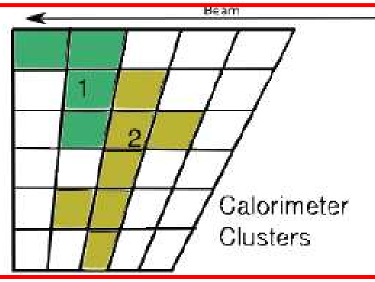


“Look-Elsewhere” Effect needed for correct interpretation.
SEVERAL MASS hypothesis tested not just ONE MASS but.
The statistical significance is diluted by the number of threshold crossing.

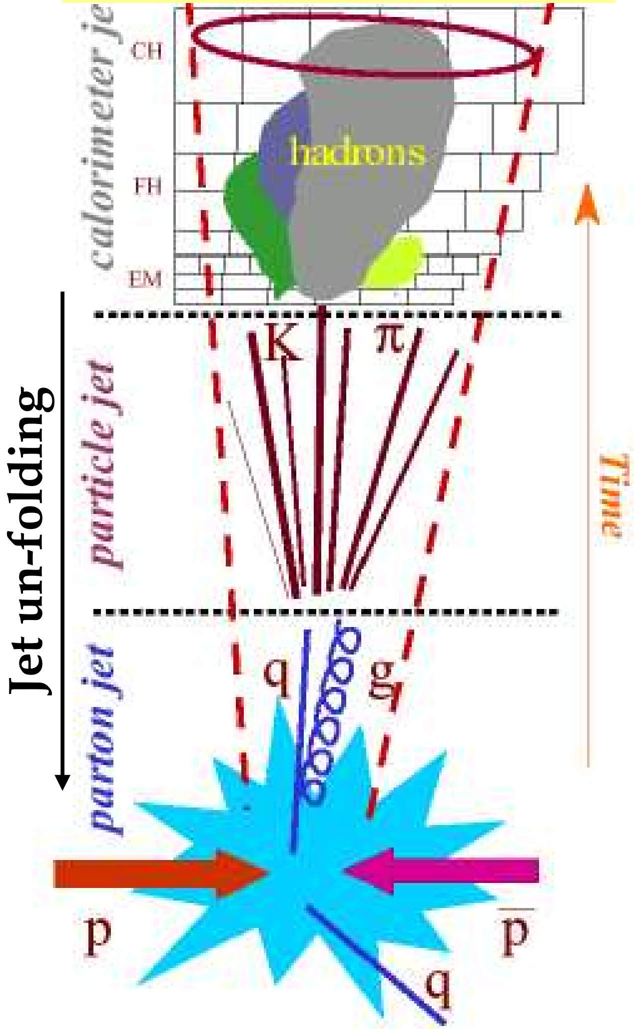
JETS Reconstruction

Topological clusters ($E>n\sigma_{Noise}$) and tracks merged with anti-kt ΔR=0.4-0.6:

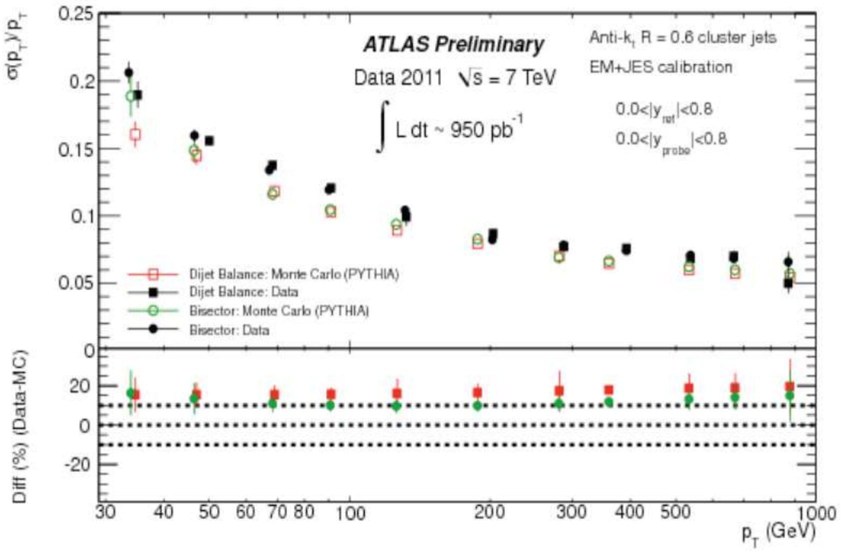
$$d_{ij} = min(\frac{1}{p_{Ti}^2}, \frac{1}{p_{Tj}^2})\frac{\Delta R_{ij}^2}{R^2}$$



Acceptance Calculation: MC + Scale Factors



- Energy Scale corrections based on MC and test beam
- JES: EM scale + rescale to Truth (few %)
- Resolution from di-jet balance
- Systematic from di-jet and γ-jet



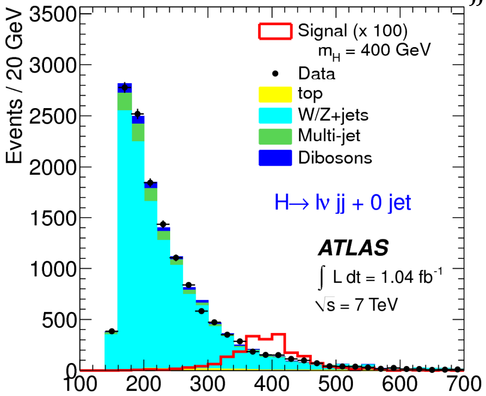
JET energy resolution 10% at 100 GeV

H→ WW$^{(*)}$→lνqq

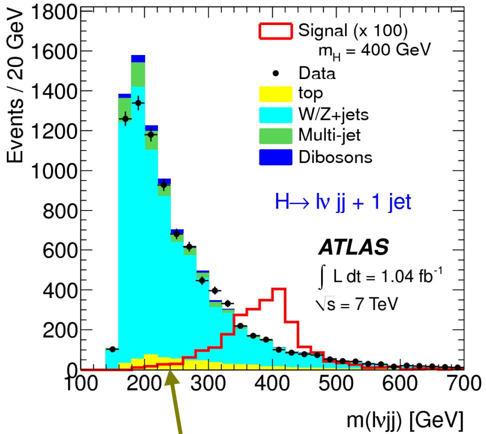
Acceptable S/B ratio at large values of M_H. Search in 240<M_H<600 GeV

Search of peak in $M_{l\nu jj}$

0 jet bin



1 jet bin



Top BG in 1 jet bin

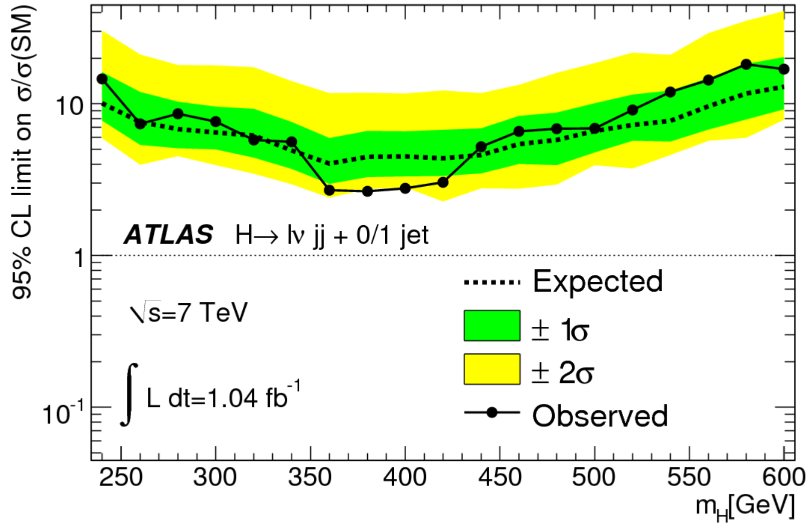
Selection:

- Exactly one High-P_T lepton
- Large Etmiss
- **2 or 3 High-P_T jets** with a pair from W decay

Background:

- **Z/W+jets**

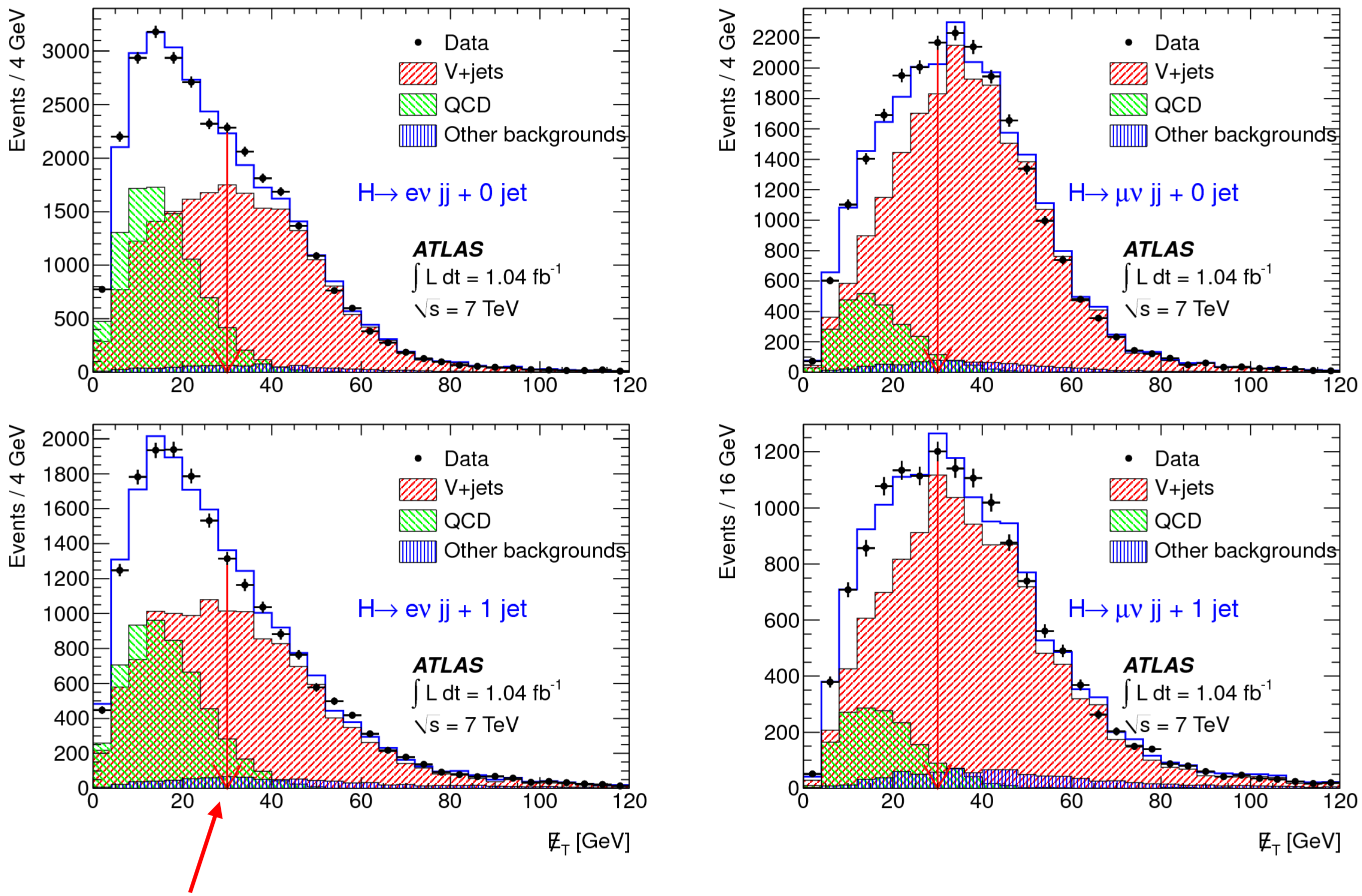
Estimate in CR by loose e and inverted μ.cuts.



Upper limit at m_H = 400 GeV is ≈ 2.7 × SM prediction

H→ WW(*)→lνqq Phase Space Slicing

e channels | μ channels



0 jet bin

1 jet bin

MET cut remove QCD multi-jets and leave W/Z+jets

Intermediate and high mass search with ZZ

- $H \rightarrow ZZ^{(*)} \rightarrow llll$ (golden channel)
- $H \rightarrow ZZ^{(*)} \rightarrow ll\nu\nu$
- $H \rightarrow ZZ^{(*)} \rightarrow llqq$

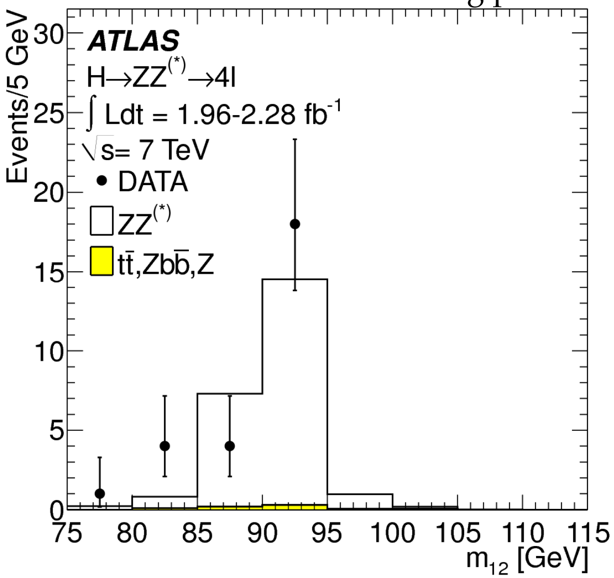
$H \rightarrow ZZ^{(*)} \rightarrow 4l$

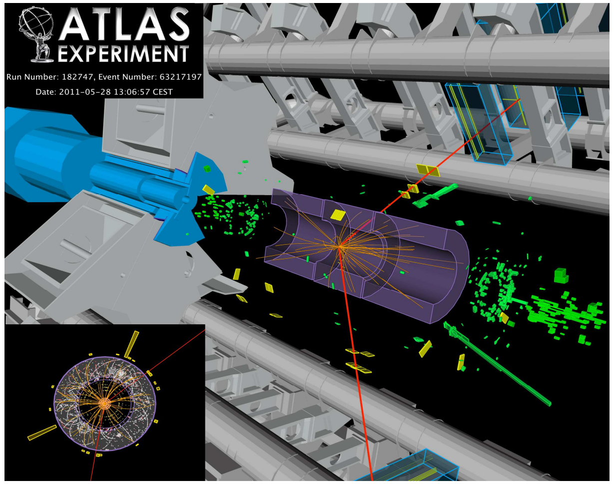
The "golden mode" is very clean but low rates

Selection:

- Two isolated same-flavour opposite charge di-lepton pairs: 2e2e,2μ2μ,2e2μ
- One di-lepton from Z
- Veto low invariant mass pairs (remove Drell-Yan pairs)
- For $m_{4l}<2m_Z$ small lepton impact parameter (from same primary vertex)

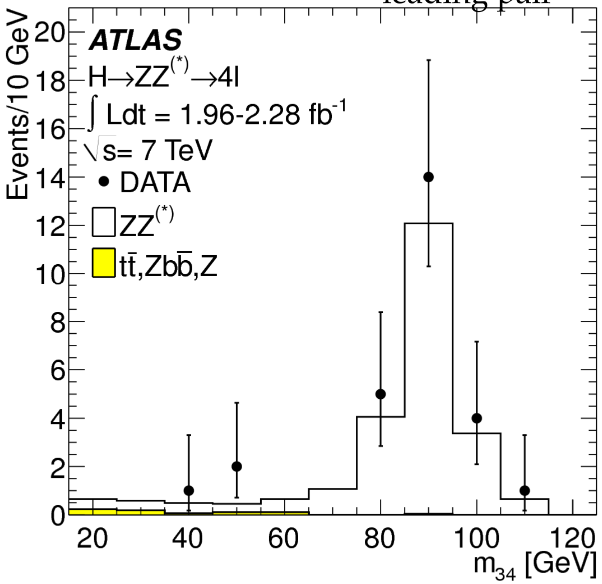
Distribution $M_{\text{subleading pair}}$





m_{ee}: 85.9 GeV $m_{\mu\mu}$: 85.5 GeV
m_{4l}: 210 GeV

Distribution $M_{\text{leading pair}}$



Mass resolution with charged leptons

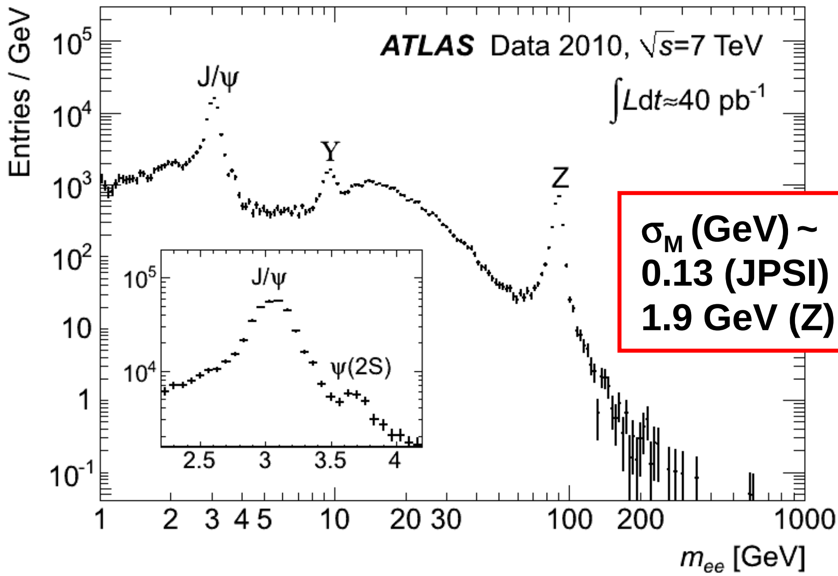
ELECTRON:
- ECAL clusters matched to ID track.

UNCONVERTED PHOTON:
- ECAL clusters not matched to ID tracks.

CONVERTED PHOTON:
- ECAL clusters matched to ID tracks from conversion vertex or scattering.

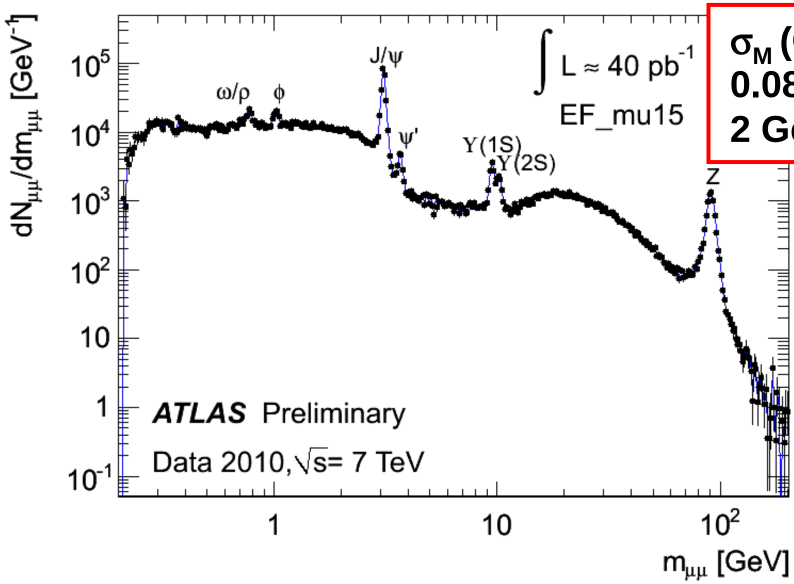
MUON COMBINED:
- global refit of all hits after statistical matching of ID and MS tracks.

MUON SEGMENT TAGGED:
- global refit of all hits after statistical matching of ID tracks and MS segments.



σ_M (GeV) ~
0.13 (JPSI)
1.9 GeV (Z)

e^+e^- invariant mass with ID+ECAL



σ_M (GeV) ~
0.08 (JPSI)
2 GeV (Z)

$\mu^+\mu^-$ invarian mass with ID+MS

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

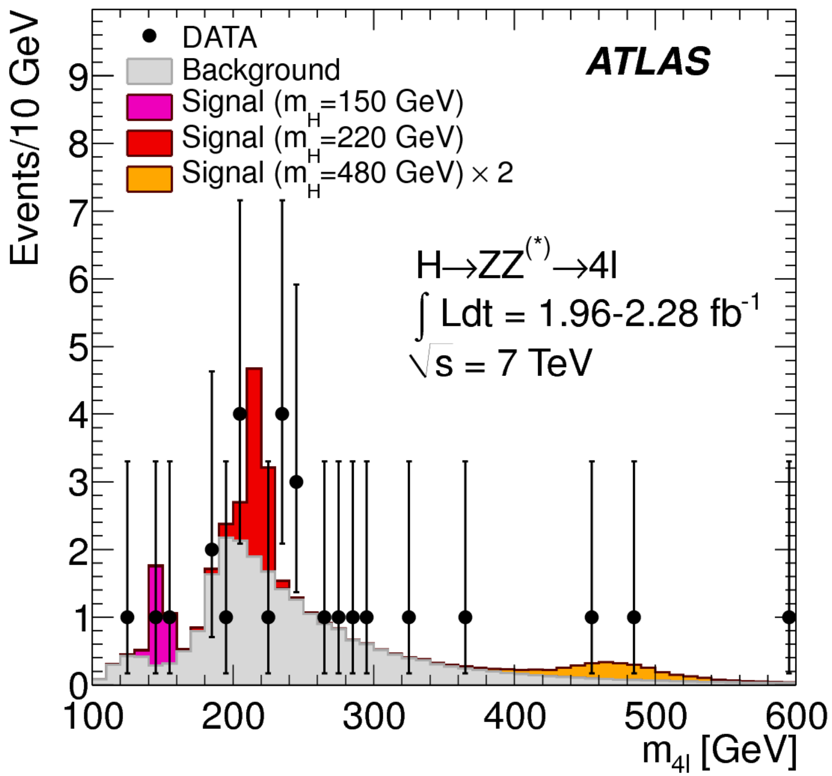
- Irriducible $ZZ^{(*)}$ is dominant
  - MC prediction (**qq/qg→ZZ NLO and gg→ZZ LO**)
  - Theory uncertainty 15%
  - Scaled by **σ_{ZZ}/σ_{Z} from measured Z** yield

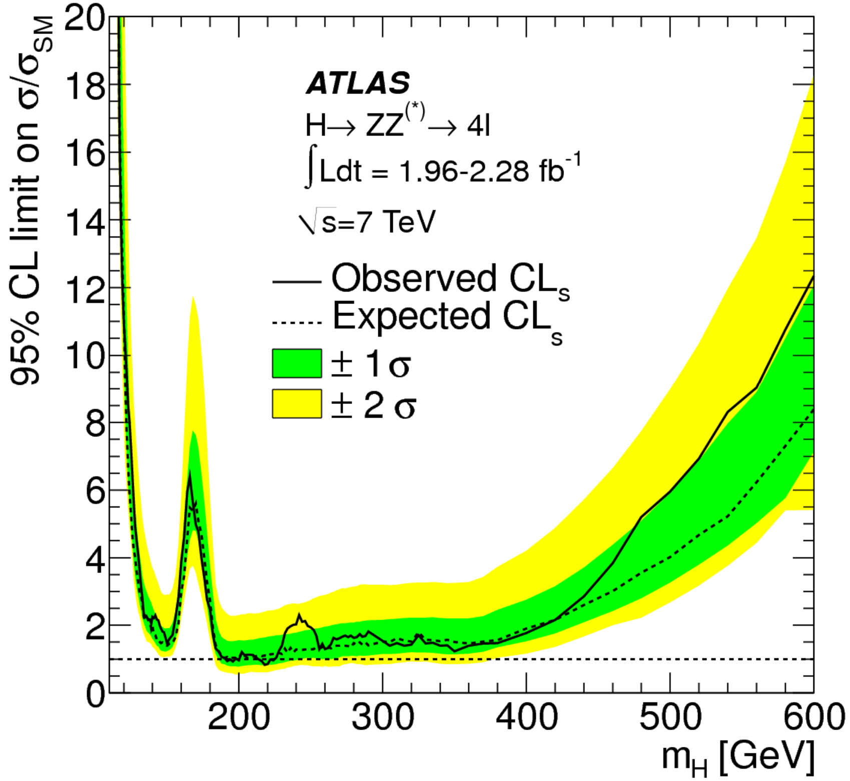
- Top from MC prediction small (theory uncertainty 10%)
  - Yield validated in control region by opposite-charge and oppostive flavor **$e^{+(-)}\mu^{-(+)}$ plus 1 or 2 leptons.**

- Z+jets, Z+bb normalized to data using control regions
  - Control region: **clean Z + 2nd lepton pair with inverted isolation and impact parameter requirements**
  - Uncertainty: 20-40% (dominated by statistics in control regions and extrapolation to signal region)

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

Search of peak in $\mathbf{M_{4l}}$





- Follow quite well the SM cross-section
- Some fluctuations due to single events
- Higgs mass around 200 GeV values already excluded

$H \rightarrow ZZ^{(*)} \rightarrow ll\nu\nu$

Final state characterized by di-lepton from Z with large transverse missing energy.
Significant signal/background ratio at large mass from 200 to 600 GeV.

Selection (NB. Same final state as $WW^{(*)} \rightarrow l\nu l\nu$):

- Select Z
- Very large ETMiss > 66 (82) GeV low (high) mass analysis
- Topological cuts to suppress W/Z+jet and QCD multi-jet background
  - Low H mass: $1 < \Delta\phi(ll) < 2.64$ (slow Z)
  - High H mass: $\Delta\phi(ll) < 2.25$ and $\Delta\phi(MET,ll) > 1$ (boosted Z)

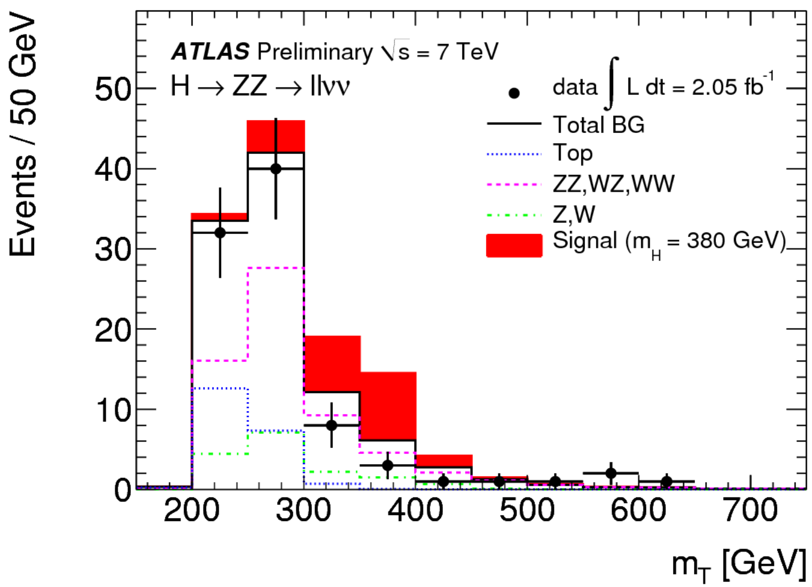
Background

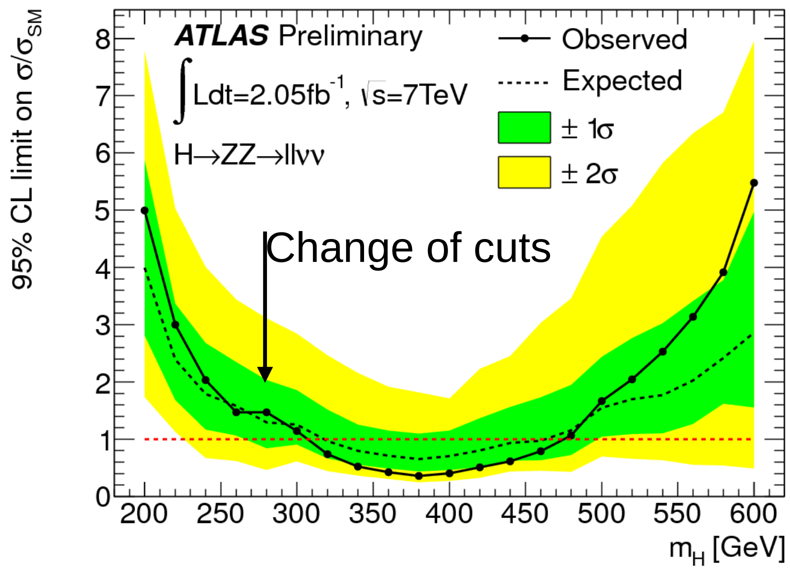
- Irreducible di-bosons. Normalization from MC
- QCD multi-jet, W/Z+jets, top. Normalization from data

$H \to ZZ^{(*)} \to ll\nu\nu$ Exclusion limits

The discriminant is the transverse mass M_T where the missing P_T assumed from a Z

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





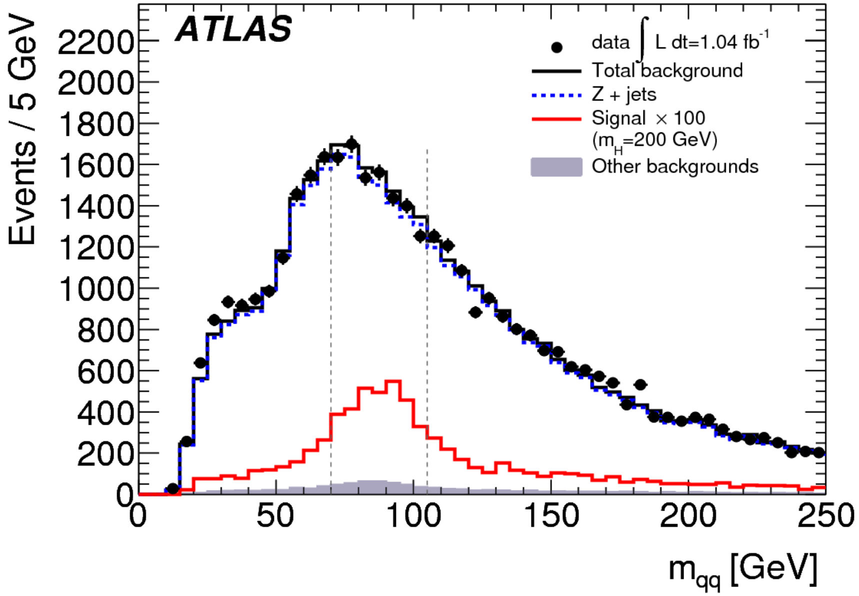
- SM Higgs boson in the range 350 GeV < M_H < 450 GeV, can be excluded at the 95% confidence level.
- The expected limit is lowest around a M_H=360 GeV where it is 1.3 x σ_{MS} and the data "under fluctuate".

$H \rightarrow ZZ \rightarrow llqq$

Acceptable signal-to-background for mass range $m_H > 2m_Z$.

Selection:

- Z selection with P_T>20 GeV
- Third lepton veto and E_T^{miss}<50 GeV
- At least 2 jets with a pair caming from Z
- 4 channels: (ee. μμ) x (b-untagged, b-tagged)

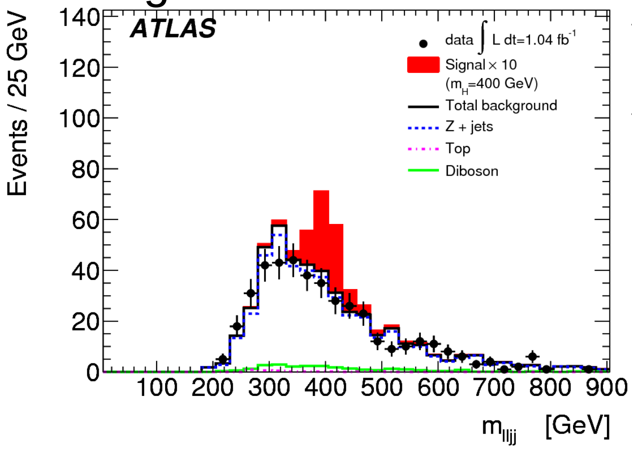


Background:

- QCD Z+jets from di-jet side-band
- Others from MC

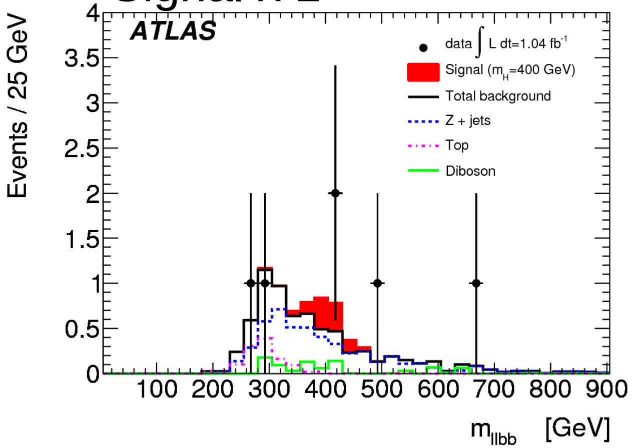
H→ ZZ→llqq Exclusion limits

Signal x 10



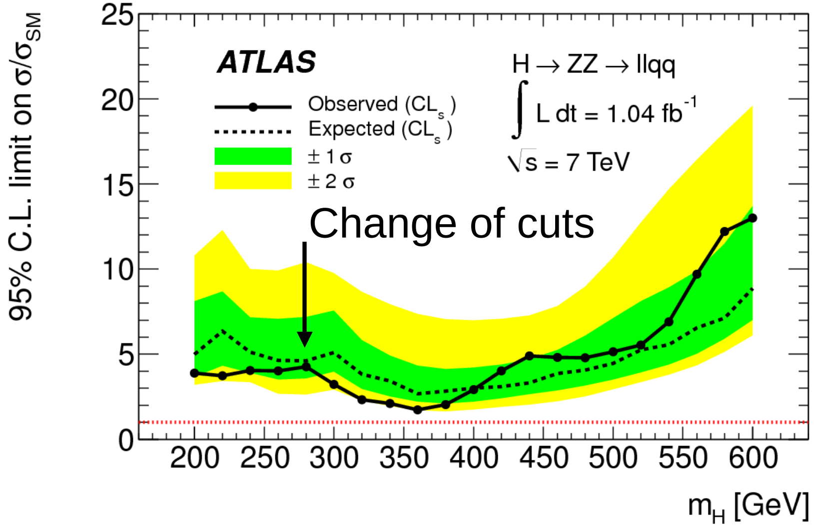
Untagged jet
At most 1 b-jet

Signal x 1



Tagged
2 b-jets

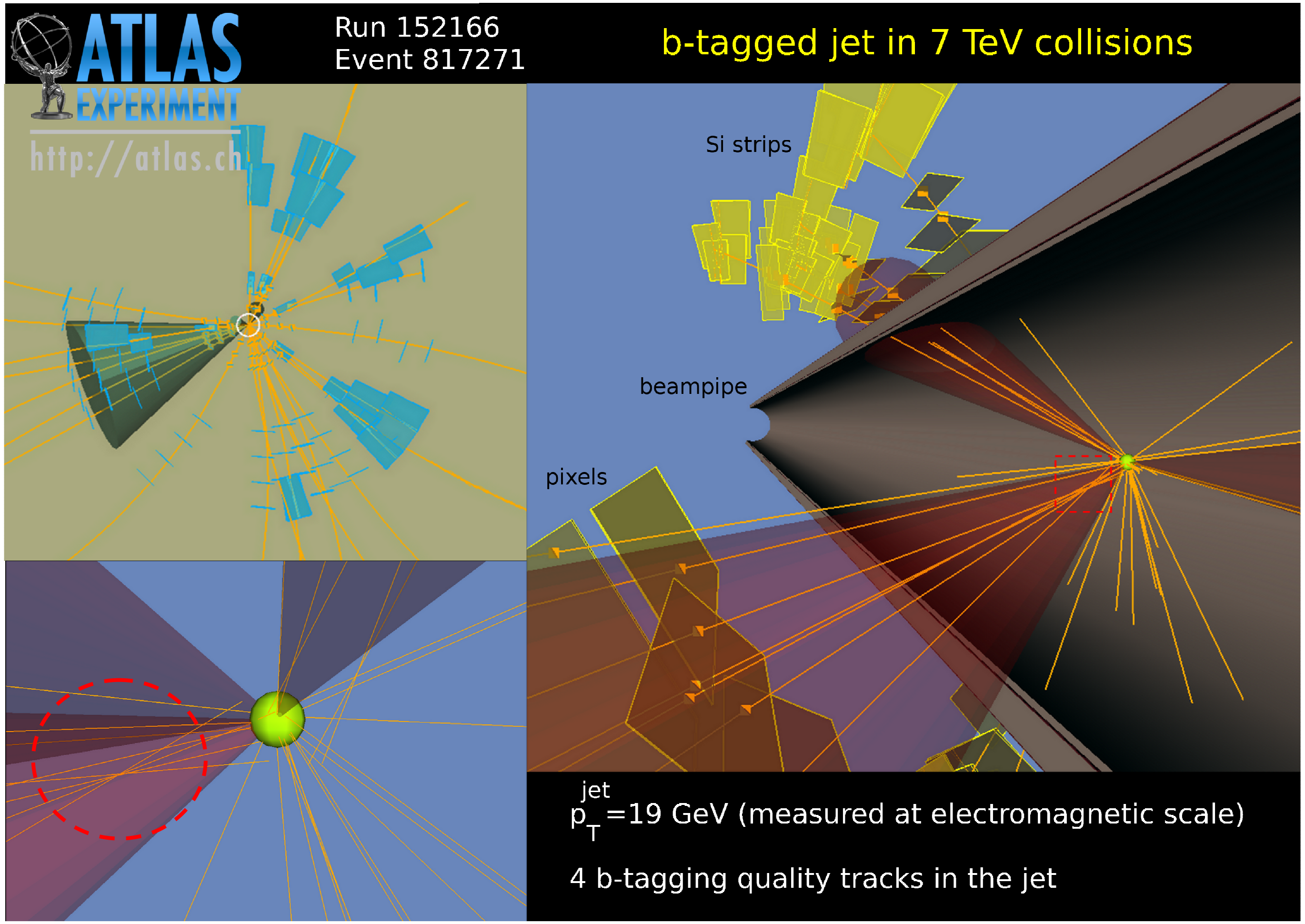
Search of peak in M_{lljj} with M_{jj} scaled to M_Z



Good sensitivity in a large mass range
Obs. limit 1.7 σ_{MS} at M_H=360 GeV (Exp. limit 2.7)

b-jet identification

Most efficient b-tag algs based on Secondary Vertex (SVT) in jet.



- SV0: SVT signed decay length
- TrackCount: SVT number of tracks
- JetProb: Probability all tracks from PVT
- IP3D+JetFitter: imp. par. signif. + b and c weak decay topology
- …

Eff ~ 50% mistag<1% measured with muon tagging in s.l. decay.

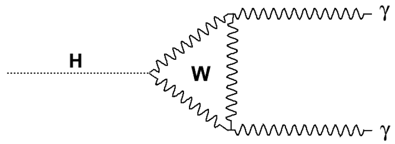
We need many guns to fight Pile-Up

Low mass search

- $H \rightarrow \gamma\gamma$ (most sensitive)
- $W/Z+H \rightarrow ll/l\nu+bb$
- $H \rightarrow \tau\tau$ (very reach and H MSSM search)

$H \rightarrow \gamma\gamma$

- Rare decay throws W/t loops: BR=0.2%
- Clear signature
- Best for low mass



$\gamma\gamma$ Selection:

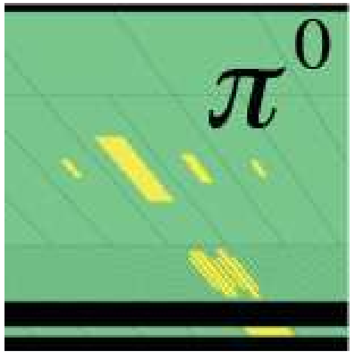
- HighP_T, high quality, isolated photons
- $|\eta_{1,2}|<1.37$ and $1.52 < |\eta_{1,2}| <2.37$ where first sampling has high granularity.
- 5 channels: (γ direction) x (conversion status). Fully correlated systematic.

Resolution:

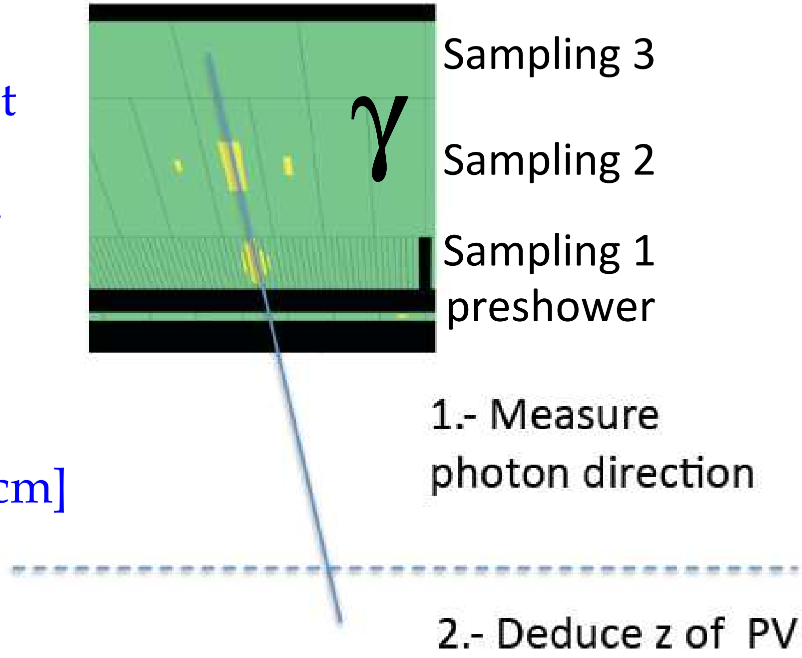
- δE=1.3 GeV from Z(ee) calibration
- δz=1.5 cm from constrained vertex [$\delta m(\theta)$ = 1.4 GeV from beam spread dz = 5.6 cm]

- $m^2 = 2E_1E_2(1-\cos\vartheta) \cong E_1E_2\vartheta^2$
- $\delta m/m=(\sqrt{2}\delta E/E) \oplus \delta\vartheta/\vartheta$~1.7GeV/120 GeV

↑ negligible

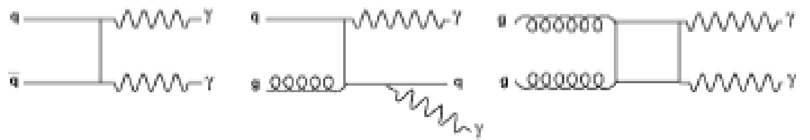


γ identification from lateral and longitudinal shower shape in ECAL.



H→γγ prompt background

Irreducible background: pp→γγ + X



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

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

Reducible background: pp→γj , jj+ X

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

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

Signal σ = 0.04 pb

Prompt γ-γ

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

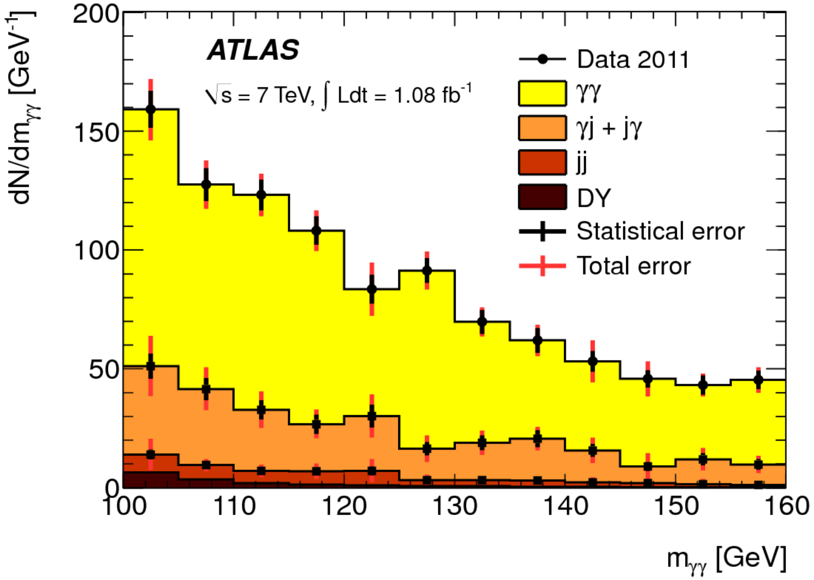
γ-jet $\sigma \approx 1.8 \times 10^5$ pb
jet-jet $\sigma \approx 4.8 \times 10^8$ pb

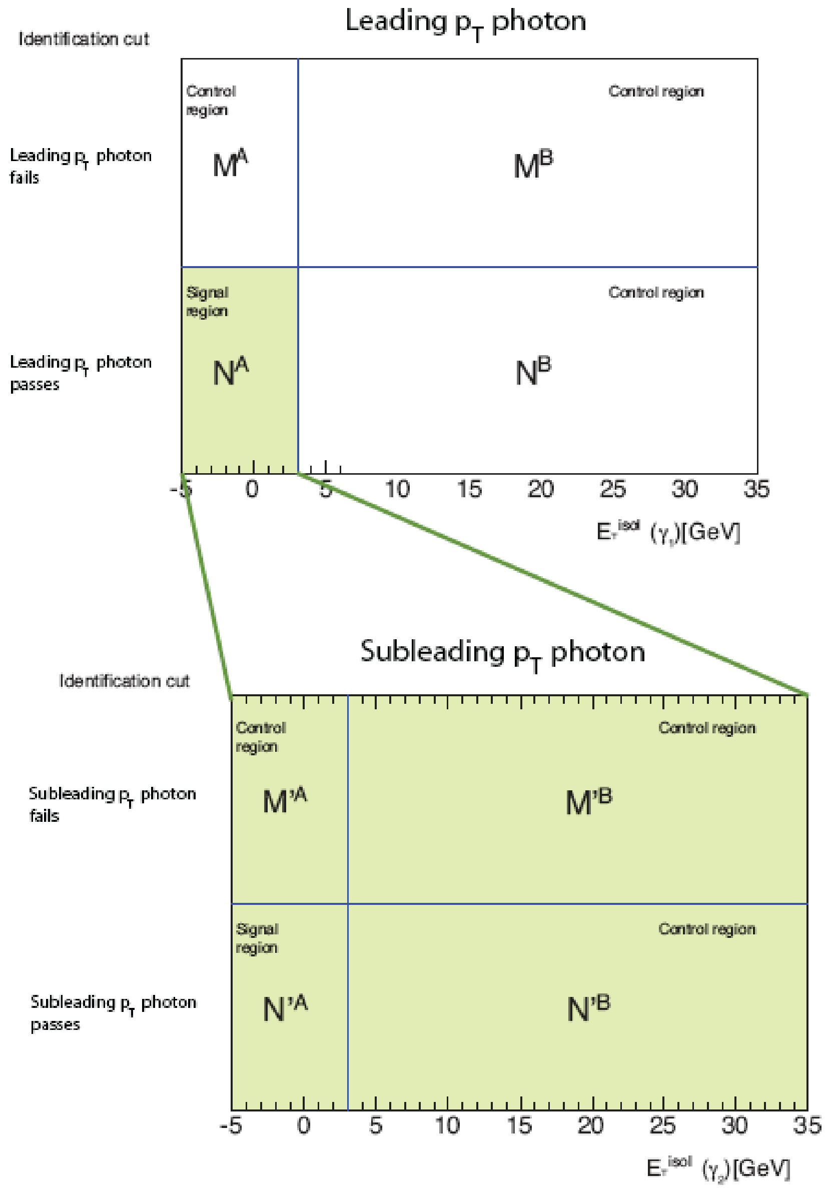
γ-jet need rejection R~O(10^4)
jet-jet need rejection R~O(10^7)

Main background is from leading π^0's

H→γγ control region

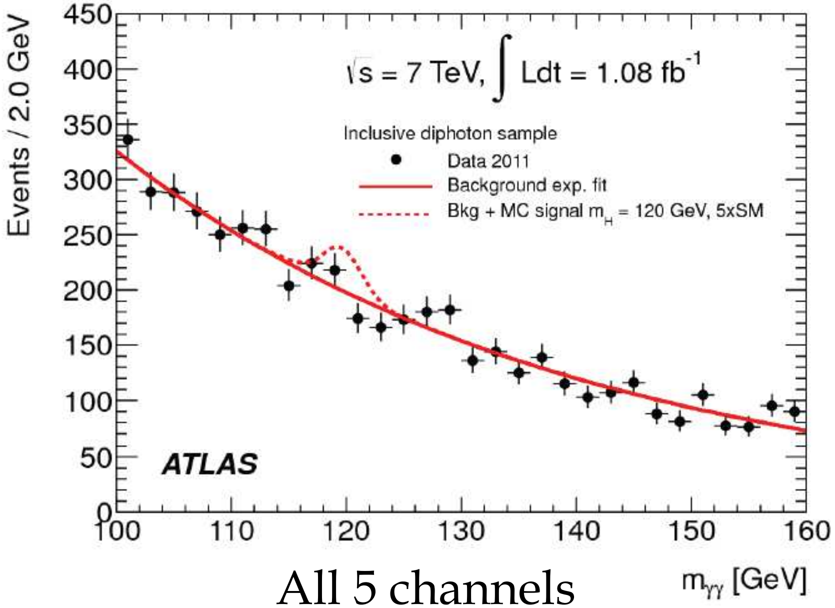
- Measure γγ, γj, and jj background from control region
- Analyzing photon isolation and loose-tight identification criteria.



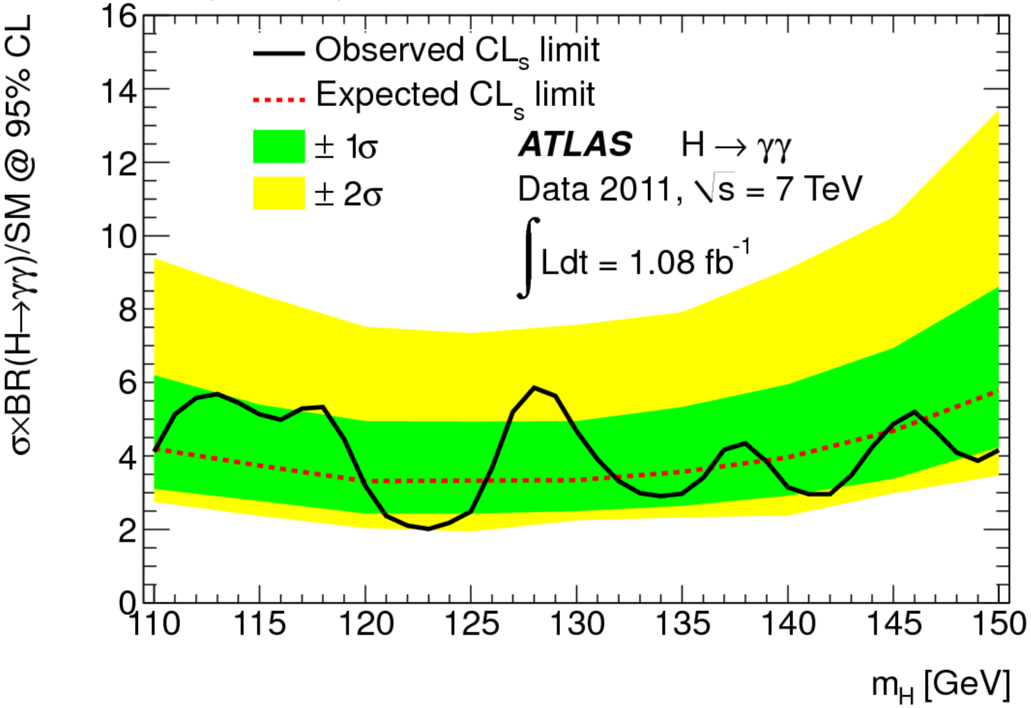


$H\to\gamma\gamma$ Exclusion limit

Background from $\gamma\gamma$ invariant mass unbinned distribution (the only discriminat)
Signal modeled by a BW convoluted by a Crystal Ball + wide Gaussian



All 5 channels

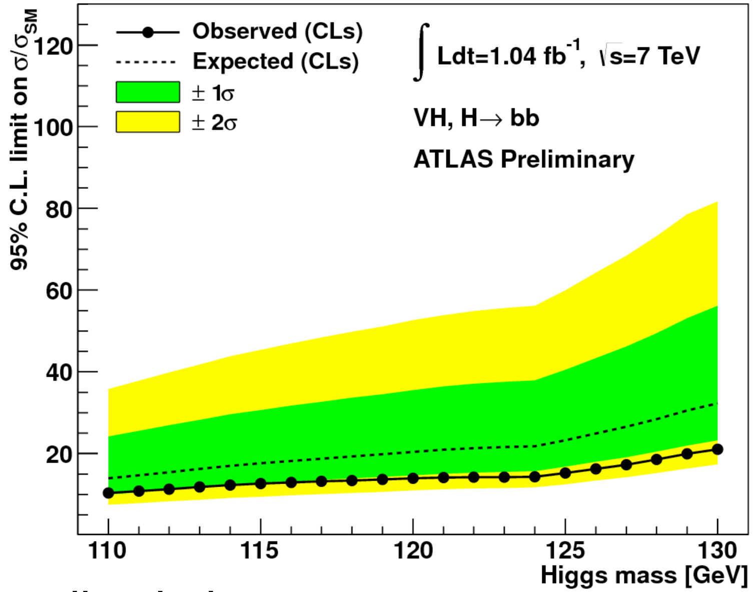


Systematic uncertainties	
Signal yield	±12%
Mass invariant mass resolution	±14%
Background modeling, $m_{\gamma\gamma}$ = 110(150) GeV	±5(±3) events

- 4 x σ_{SM} x BR is excluded at 95% CL
- Strong implication on fermiophobic Higgs where $\gamma\gamma$ is expected strongly enhanced.

W(Z)+H→ lν(l)+bb

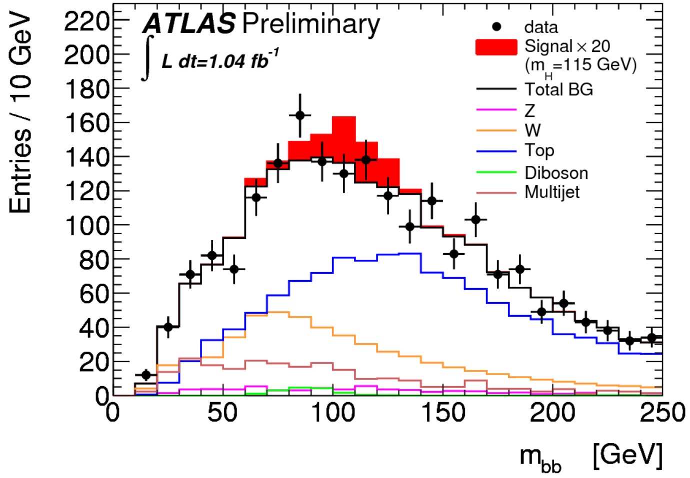
Dominant decay at low mass 110-130 GeV.
QCD jet BG makes inclusive search impossible and in association with W,Z and ttbar challenging.



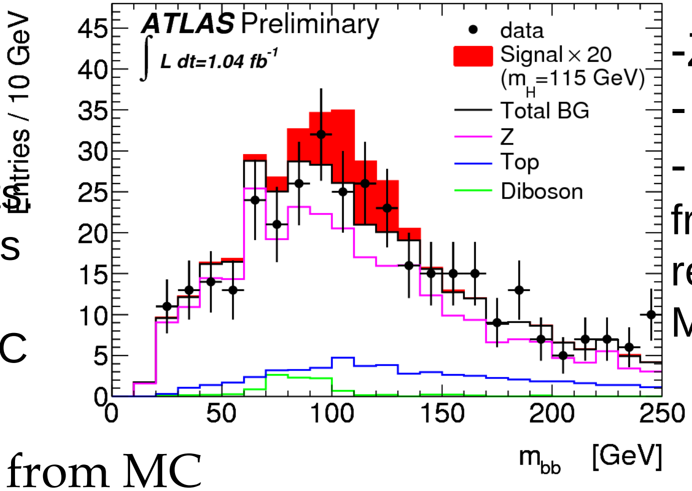
Selection:

- W or Z leptonic decay
- **Exactly 2 b-jets** P_T>25 GeV

bb invariant mass is the discriminant



- WH cuts.
-Veto ttbar
-BG: ttbar, W+j,QCD jets. Simultaneous fit in control regions of MC template



-ZH cuts.
- Veto MET
- BG: Z+jets from control region with MC shape.

Other BG from MC

SM $H\rightarrow\tau\tau$

Promising channel searches in the mass range m_H=110-150 GeV.
Small background for VBF production but lower signal production rate.

Several channels: $ll4\nu$ and $l\tau_{had}3\nu$ (τ_{had} larger BR)

Selection for leptonic-leptonic decay $ll4\nu$:

- High-P_T opposite sign lepton pair: $\mu\mu$, ee, μe.
- High-P_T jet (> 40 GeV) improve S/B in VBF due to H boost
- Moderate E_T^{miss}
- Several topological cuts to increase S/B

Background: Z/W+jets, di-bosons, ttbar, t, QCD jets.

- The main BG is the irriducible $Z\rightarrow\tau\tau$.
  Estimated from $Z\rightarrow\mu\mu$ data replacing muons with simulated τ's
- QCD jets and W+jets also estimated from data.
- All other contributions estimated from MC.

SM H→ττ Collinear approximation

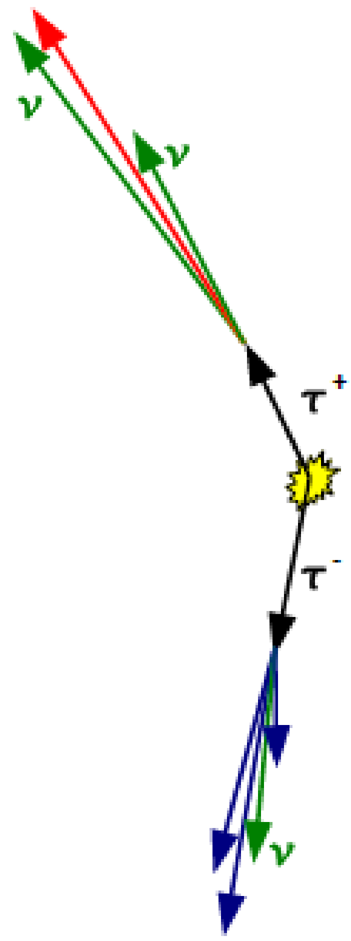
Collinear approximation: l||ν

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

x = neutrino momentum fraction in the decay

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

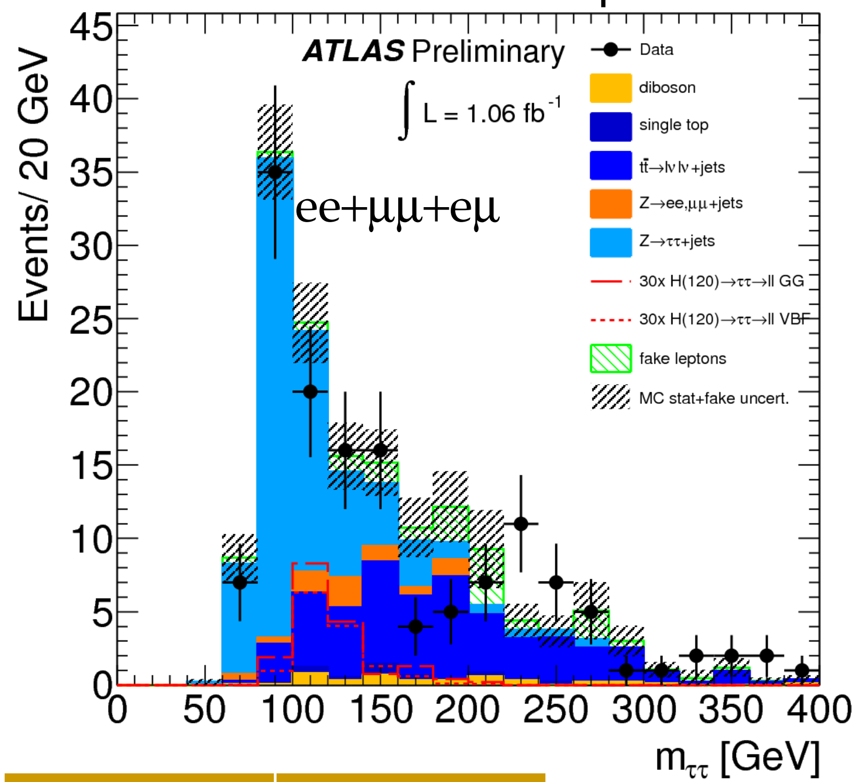
→ **invariant mass two leptons**



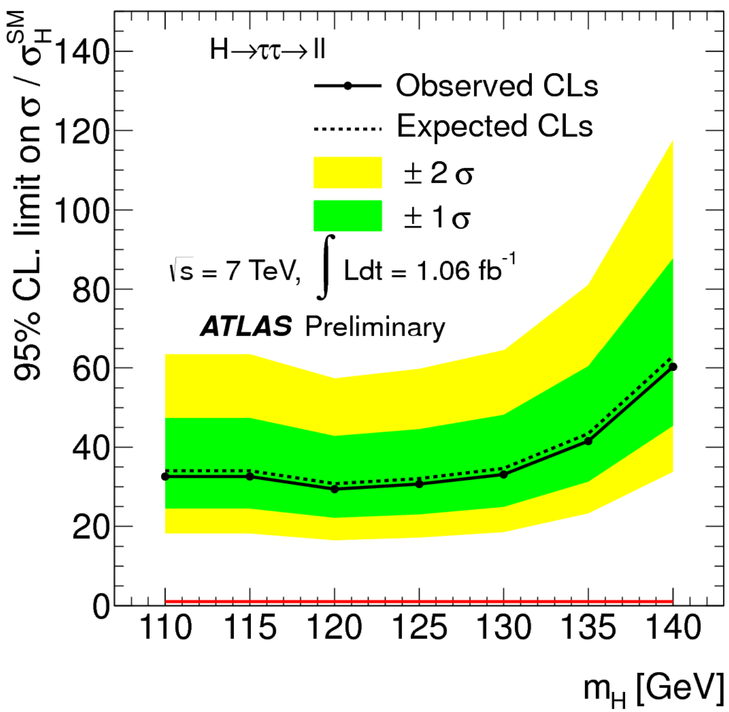
The closure of the kinematics sometime fails

SM H→ττ Exclusions limits

ττ invariant mass plot



Counting analysis



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

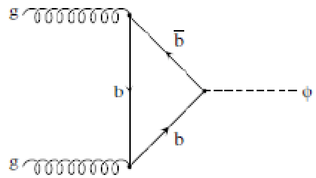
Important Systematic uncertainties :

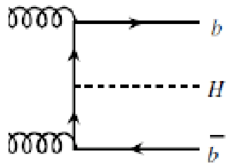
- Dominated by the Jet Energy Scale (JES):
  BG: -9.8%+7.0% , Signal (M_H=120 GeV) -4.1% +7.8%
- Important contribution also from E_T^{miss}

MSSM h/H/A→ ττ

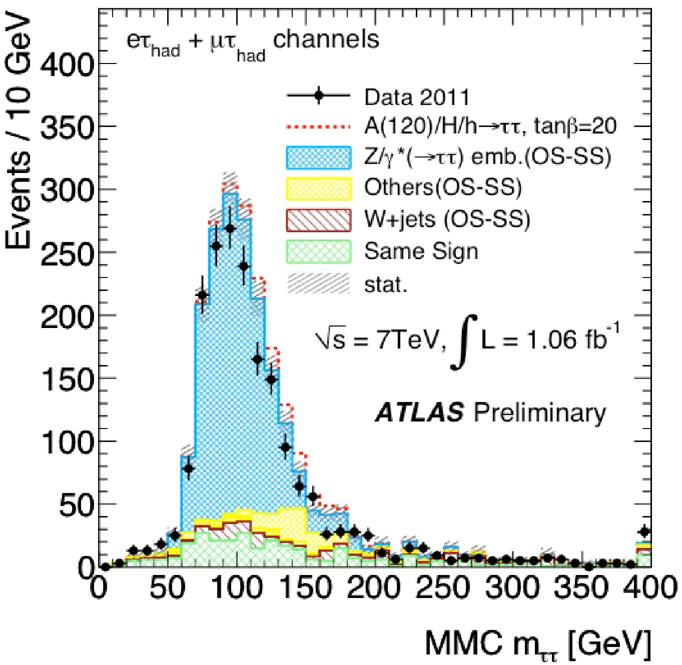
Coupling to 3rd family enhanced at large tanβ:

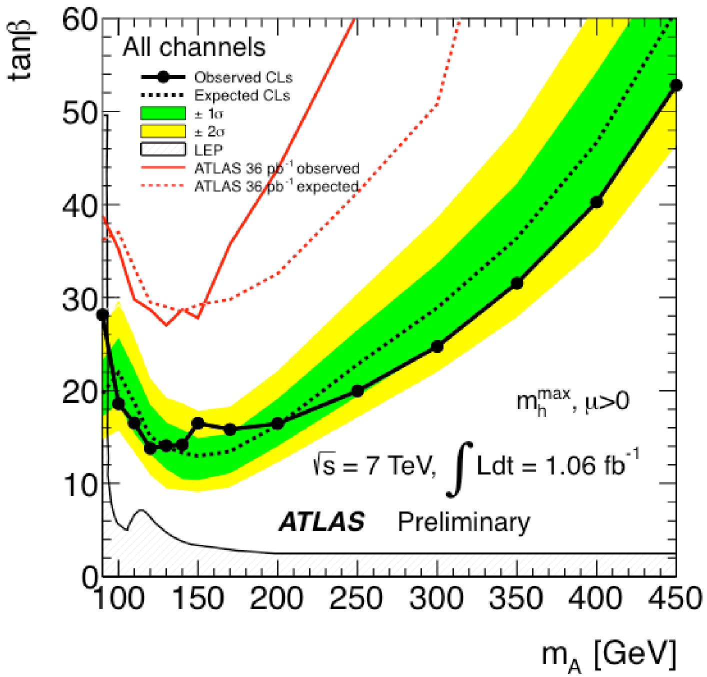
- gg → h/H/A and associated b production
- h/H/A → ττ decay most promising channel





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



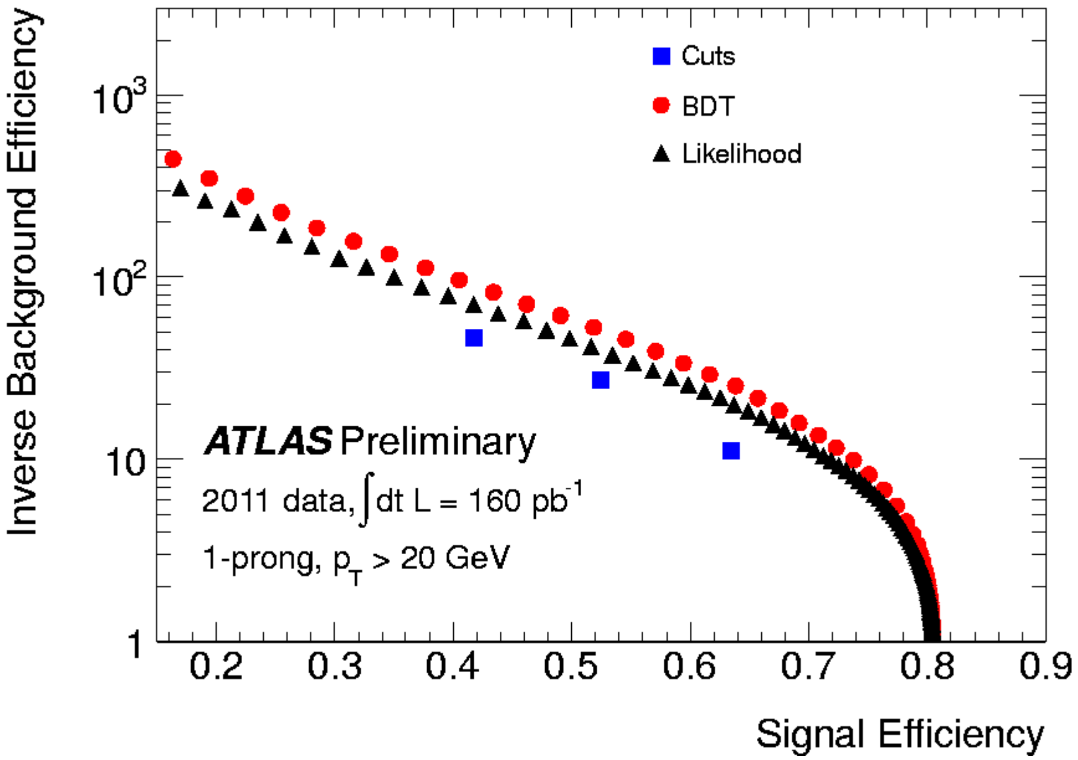


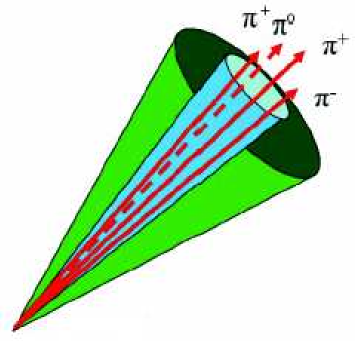
Final states are: eμ4ν, $l\tau_{had}$3ν and $\tau_{had}\tau_{had}$2ν.
The $\tau_{had}\tau_{had}$ invariant mass is reconstructed with methods more sophisticated than collinear approximation

Expected and observed exclusion limits based in the m_A − tan β plane derived from the combination of the analyses for the eμ4ν, $l\tau_{had}$3ν and $\tau_{had}\tau_{had}$2ν final states.

τ-jet identification

BG eff^{-1} vs hadronic τ eff



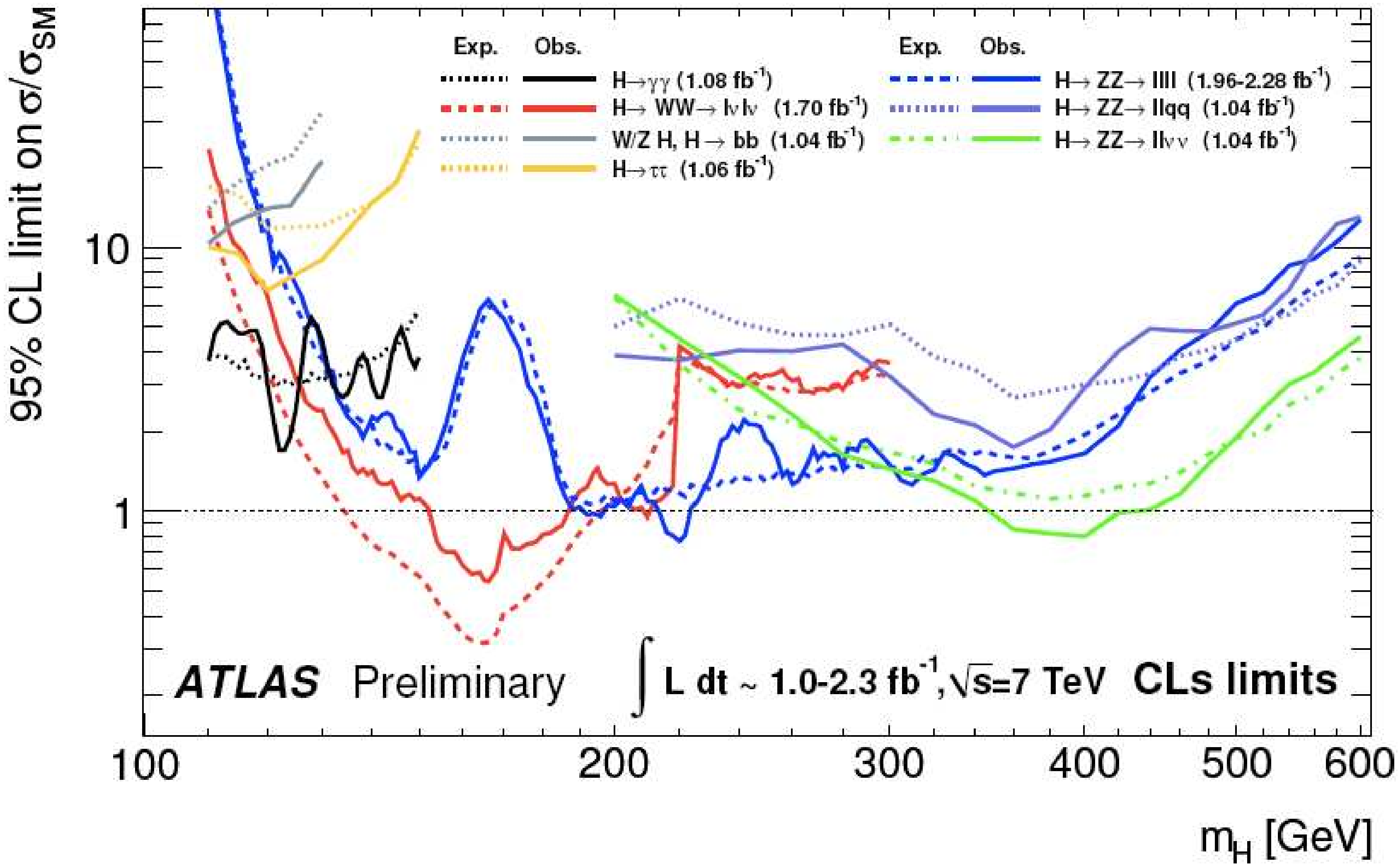


hadronic τ

- 1 or 3 tracks
- SVT
- narrow jet
- Large EM frac.

Fighting the Pile-up: beyond cut-based ID to :
LogLikeliHood, BoostedDecisionTree, NeuralNetwork

ATLAS SM Higgs search



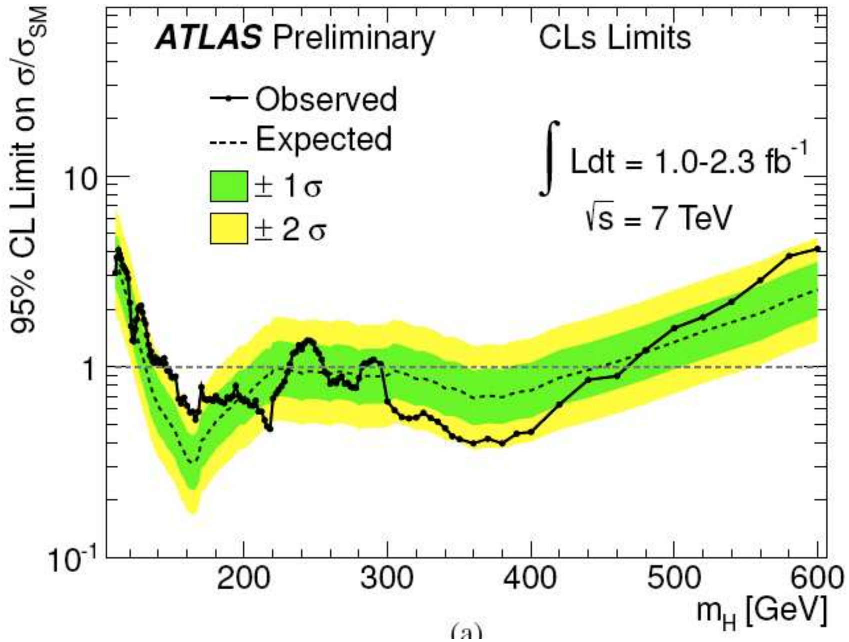
ATLAS SM Higgs combination

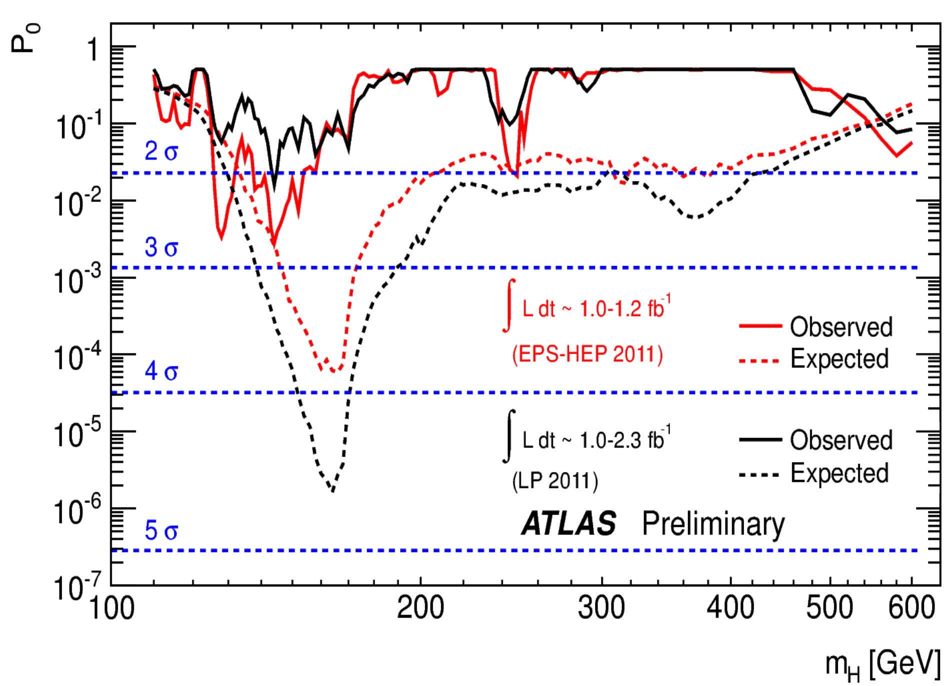
The Likelihood is the product of individual likelihood

$L(\text{Data} \mid \mu,\theta)=[\text{Poisson}(Ni \mid \mu s_i(\theta) + b_i(\theta))]\text{pdf}(\theta)$

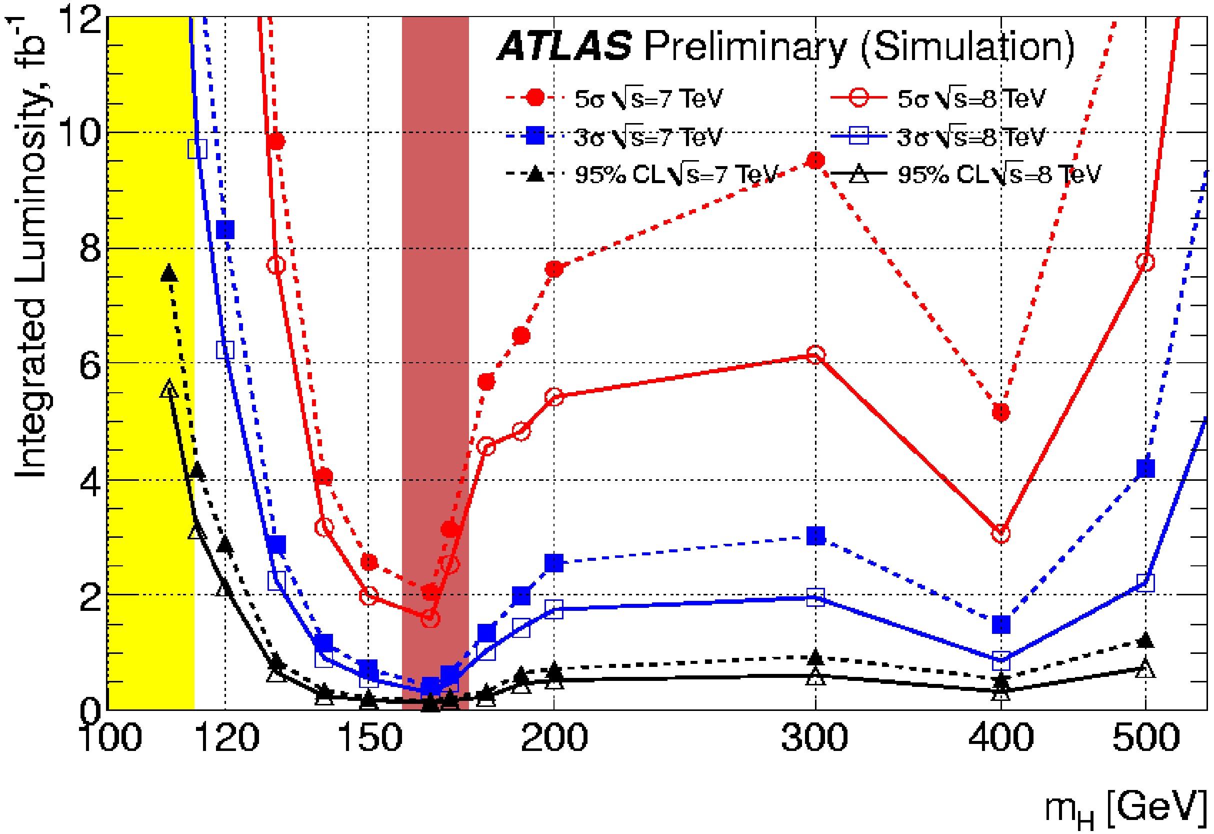
N=Observed, s+b= Expected, pdf = distribution nuisance parameters

Data= real data or pseudo-data





ATLAS projection Higgs search



- 2011 exclusion from LEP limit up to 500 GeV.
- 2012 3σ evidence from LEP limit up to 500 GeV.
- 14 TeV necessary for 5σ discovery from LEP limit up to TeV scale.

Systematic uncertainties

Instrumental uncertainties

- Luminosity 3.7%
- Trigger and Reco efficiency
  - μ -0.5+1.2%
  - e -1+3.4%
  - γ 11%
  - τ_{had} 8.3%
  - b-tag 0.6-16%
- PT resolution 0.1-2.2%
- E scale
  - e -0.1+1.2%
  - MET/Jets -1.3+8%

Theoretical uncertainties

- Cross-section
  - QCD fact. and renorm. scale:
    - GF= -7%+12%
    - VBF, associate V = +/-1%
    - associated ttbar = -10+5%
  - PDF+alpha_s:
    - GF, associated ttbar = +/-8%
    - VBF, associate V =+/-4%
- Branching Fraction uncertainties are small with respect to cross-section ones
- For large M_H (not BW line-shape, off-shell terms, and interference with EW BG) introduce (150%)xM_H(TeV)^3
- Background uncertainties estimated by changing QCD scales and pdf+α_s

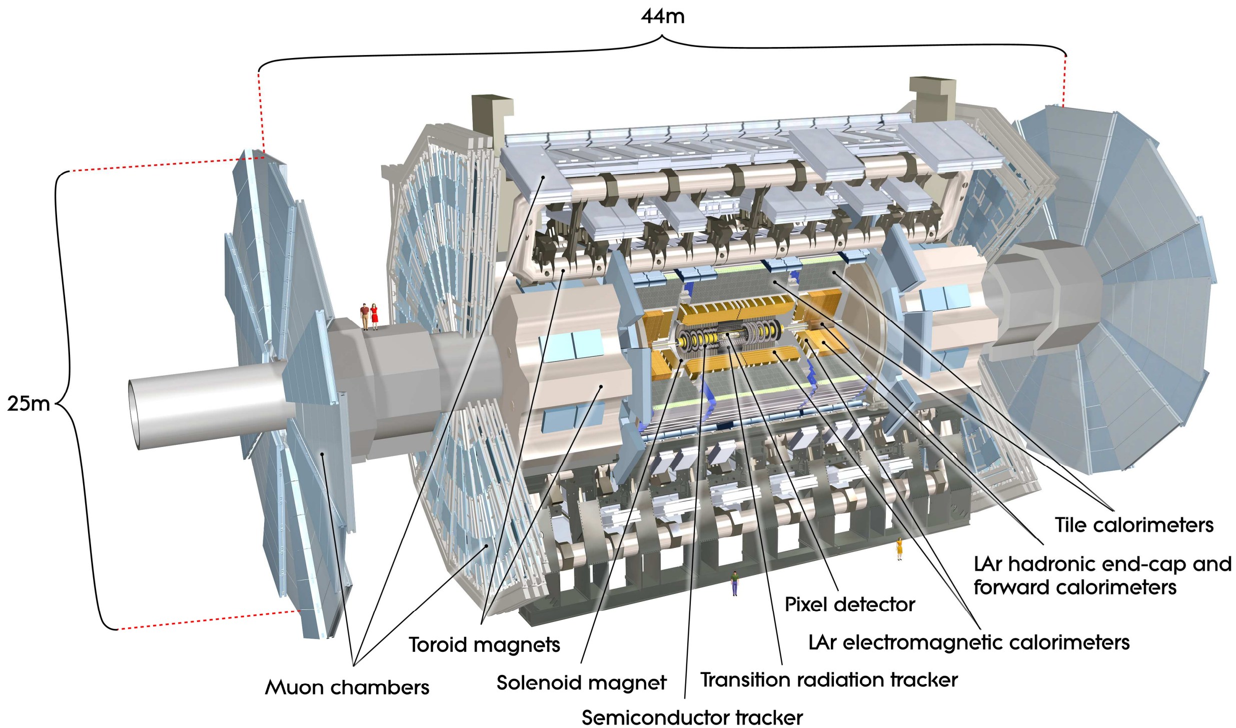
Conclusions

- Proton-proton collisions at 7 TeV and corresponding to an integrated luminosity between 1-2 fb-1 has been analyzed by ATLAS for extensive Higgs boson search
- No significant excess (< 2.1σ) is found in the mass range 110-600 GeV and 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
- A big jump in Higgs search is going to happen in few months with the integrated luminosity already available on tape (> 5 fb-1)

New ideas and analysis techniques are welcome in low mass regime to fight background (could be the breakthrough)

Back-up slides

ATLAS detector



Three trigger levels
- L1: hardware selection of high pt object from MS and CALO (40MhZ to 75 kHz)
- L2: software confirm of L1 with all systems in Region Of Interest (2 kHz)
- L3: software with precise offline reconstruction algorithms (200 Hz)

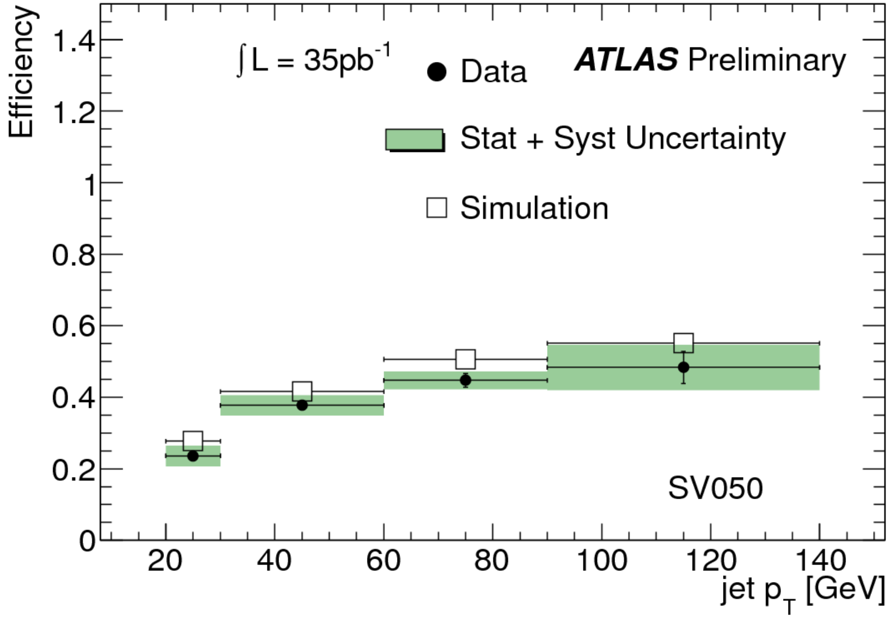
Inner detector (|η|<2.5)
- Vertexing: Pixels
- $\sigma(d_0)$~10um at high P_T
- Tracking: Strips + TRT
- 2T solenoid
- $\sigma(1/P_T)$~1.5% (low P_T)

Calorimeters (|η|<5)
- EM: accordion Pb/LAr $\sigma/E \sim 10\% E^{-1/2} \oplus 0.7\%$
- HCAL:Fe-Sci $\sigma/E \sim 50\% E^{-1/2} \oplus 3\%$
- FCAL:road-tube W-Cu/LAr ((3.2<|η|<5)

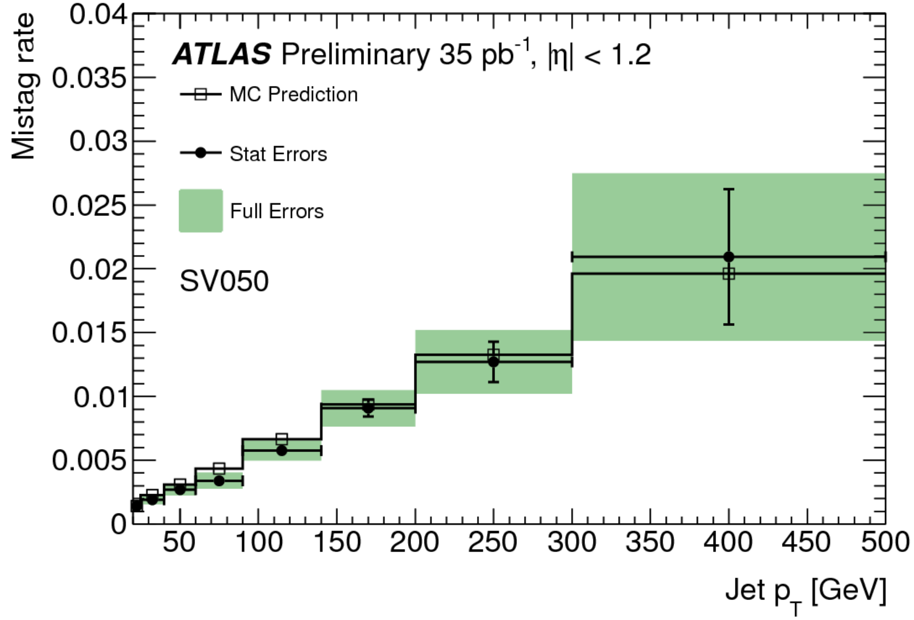
Muon System (|η|<2.7)
- Spectrometer: Monitored Drift Tube+ Cathode Strip Chamber (2<|η|<2.7)
- 4-5 Tm air core toroids σ/P_T~10% at 1TeV
- Trigger: Resistive Plate Chambert + Thin Gap Chamber σ_t~1ns

b-jet identification with SV0

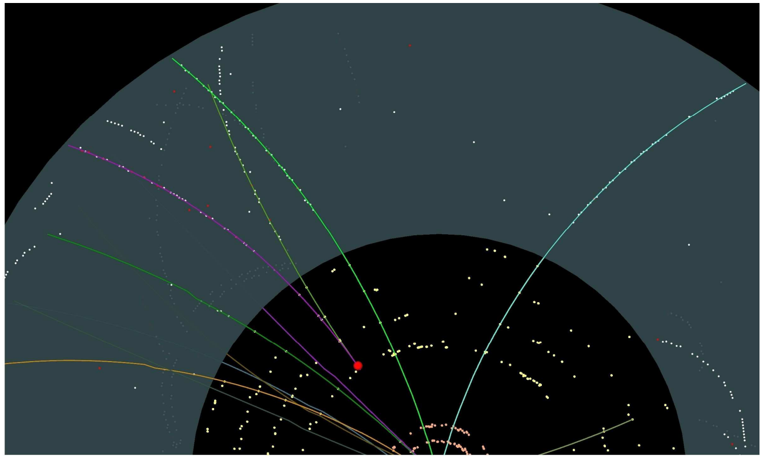
SV050 efficiency



SV050 mistag rate

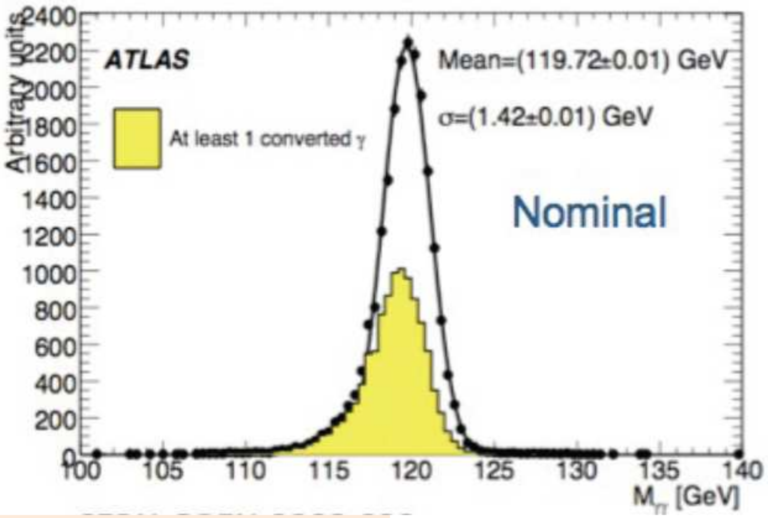


$H \rightarrow \gamma\gamma$ Resolution



- Energy resolution $\delta p \approx 1.3$ 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;
  - Use of recoil tracks less effective with large number of pile-up collisions
- Use conversion tracks as well

$\sigma \sim 1.4$ GeV



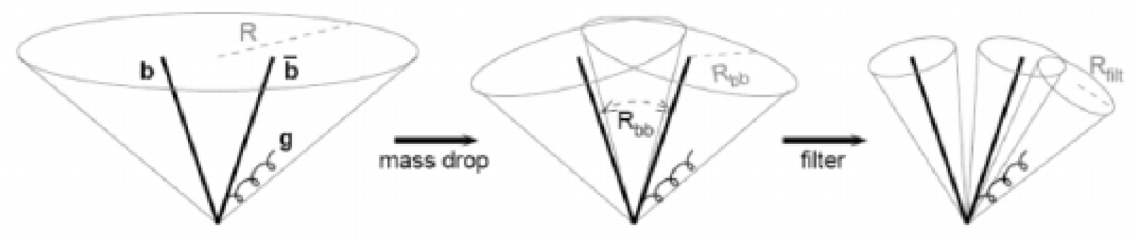
- $m^2 = 2E_1E_2(1-\cos\vartheta) \cong E_1E_2\vartheta^2$
- $\delta m/m = (1/\sqrt{2})(\delta E/E) \oplus \delta\vartheta/\vartheta \sim 1.7\ \text{GeV}/120\ \text{GeV}$

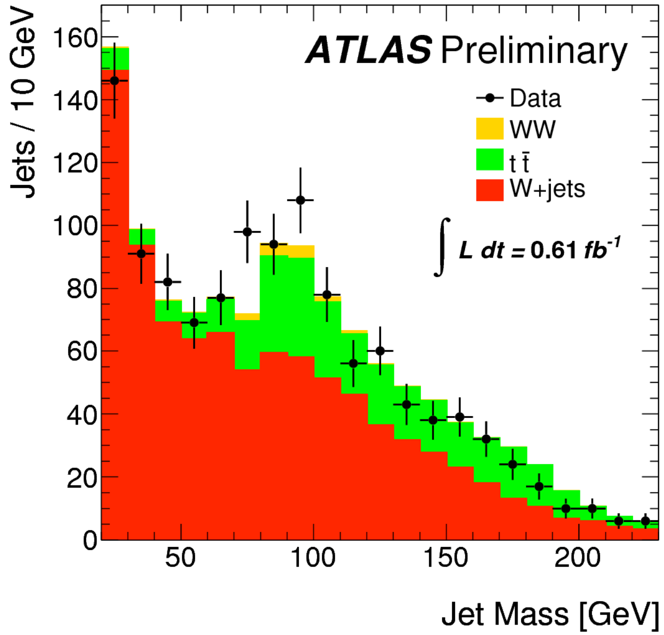
W(Z)+H→ lν(l)+bb Boosted Higgs

Improve sensitivity to H→bbbar by looking to events with boosted jet pairs
For p_T^H >200 GeV are only 5% of total yield but BG is strongly suppressed

- Reconstruct "fat" jets, using algorithms with cone sizes as large as R=1.2
- Analyze the structure of this jet, and reconstruct sub-jets with smaller R sizes
- Reconstruct jet system invariant mass from re-clustered sub-jets

Boosted JET substructure





Sub-jets mass distribution fot P_T>180 GeV in events consistent with WH→lνbb and boson decay p_T>200 GeV. The peak is consistent with W→jj (VERY PROMISING)

Other not SM Higgs search

- $t \to H^{+/-}+b \to \tau\nu+b$, cs+b MSSM charged Higgs from top decay
- $A \to \mu\mu$: not MSSM Higgs at very low mass near Υ.
- Fermiophobic Higgs
- Light Higgs to Long-Lived Neutral particles

- Higgs limits assuming a 4th generation heavy fermions