Search for the neutral MSSM Higgs Boson Decay $h/A/H \to \mu^+\mu^-$ in $7\ \mathrm{TeV}$ pp Collisions at the ATLAS Experiment

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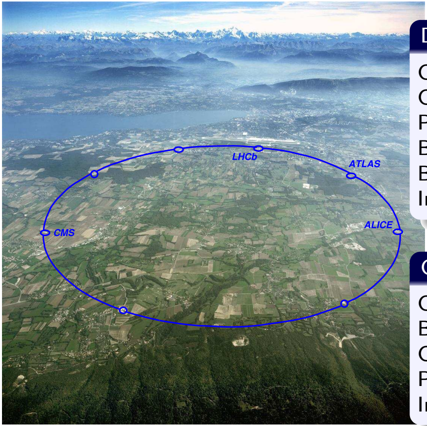


Design Operation Parameters

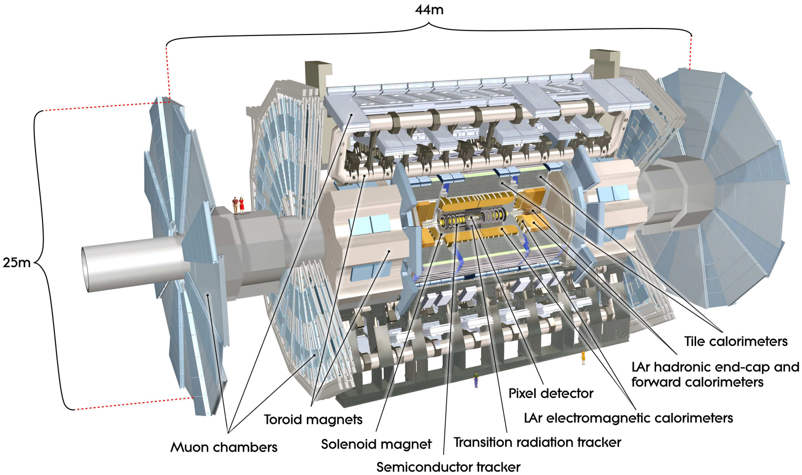
Circumference	27 km
C.M. energy	14 TeV
Peak luminosity	10^{34} cm^{-2}s^{-1}
Bunches per beam	~ 2800
Bunch crossing rate	40 MHz
Integrated luminosity	~ 100 fb^{-1}/year

Current Status

C.M. energy	7 TeV
Bunches per beam	768
Colliding bunches	~ 700
Peak luminosity	8×10^{32} cm^{-2}s^{-1}
Integrated luminosity	266 pb^{-1}

Upcoming steps in LHC operation:
Short-term: Collect ~ 5 fb^{-1} by the end of 2012.
Long-term: 15 months shutdown before increase of C.M. energy to 14 TeV.

ATLAS: Overview



Subsystem	Pixel	SCT	TRT	ECAL	HCAL	MS
Channels	$80 \cdot 10^6$	$6.3 \cdot 10^6$	$3.5 \cdot 10^5$	$1.7 \cdot 10^5$	$1.9 \cdot 10^4$	$1.1 \cdot 10^6$
Operational	0.972	0.992	0.975	0.999	0.988	0.997

ATLAS: Data Taking Status

2010 Run Summary

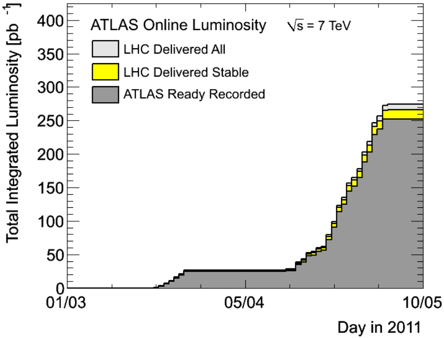
LHC Delivered All	$49\ \text{pb}^{-1}$
ATLAS Recorded	$45\ \text{pb}^{-1}$
Live Fraction	0.92

2011 Run Summary

LHC Delivered All	$266\ \text{pb}^{-1}$
ATLAS Recorded	$253\ \text{pb}^{-1}$
Live Fraction	0.95

Expected integrated luminosity recorded by the end of this year: $\sim 2\ \text{fb}^{-1}$

Total integrated online luminosity 2011



After rediscovering the Standard Model in 2010 data ATLAS will become sensitive to various New Physics processes this year.

Beyond SM Higgs Searches in ATLAS

- In ATLAS most Higgs searches beyond the SM assume the MSSM.
- Several MSSM benchmark scenarios are studied, selecting interesting regions in the parameter space.
- Most early data MSSM Higgs analyses assume the maximal mixing scenario m_h^{max}:

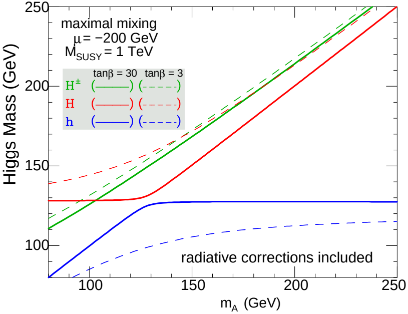
Parameter		Value $[GeV]$
Sfermion mass	M_{SUSY}	1000
Stop mixing	X_t	2000
Higgs mass	μ	-200
Gaugino mass	M_2	200
Gluino mass	$M_{\tilde{g}}$	800

- As all sfermion masses are set to $M_{\tilde{f}} > M_H$ only decays into SM particles are considered.

The MSSM Higgs Sector

- Two Higgs doublets, resulting in five physical Higgs bosons: $h/A/H$ and $H^{\pm}$.
- At tree level the Higgs sector is fully determined by two free parameters: m_A and $\tan\beta = \frac{v_1}{v_2}$.
- In m_h^{max} the lightest neutral Higgs boson is limited to $m_h \lesssim 130$ GeV.
- Two or three Higgs Bosons are degenerated in mass especially for high $\tan\beta$:
  - $m_h \approx m_A$ for $m_A < 130$ GeV
  - $m_H \approx m_A$ for $m_A > 130$ GeV
  - $m_h \approx m_A \approx m_H$ for $m_A \approx 130$ GeV

$\Rightarrow$ Measured signal has contributions from two or three resonances.



Constraints on MSSM Higgs Boson Parameters

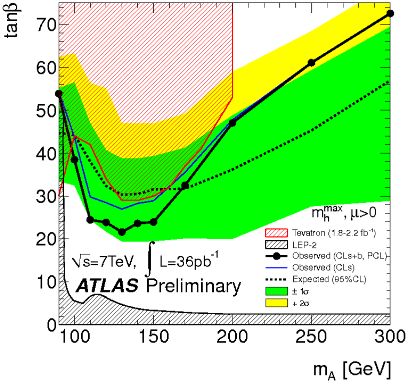
Theoretical constraint:

* Requiring Higgs couplings to fermions remain small enough for perturbative calculations: $\tan\beta \lesssim 60$.

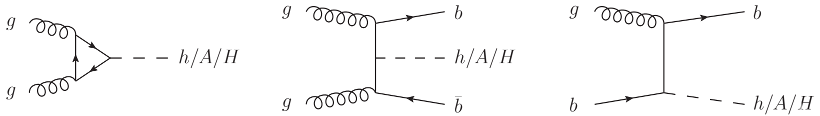
Experimental limits:

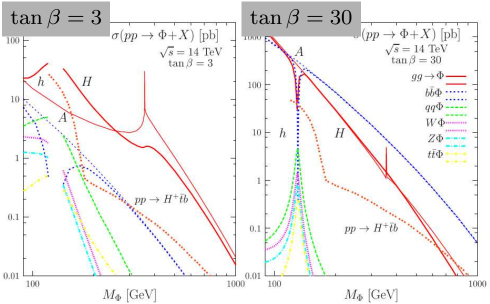
LEP	$m_{h/H} > 114$ GeV, $\tan\beta \gtrsim 5$
Tevatron*	$m_A > 95$ GeV, $\tan\beta \lesssim 35$
ATLAS*	$\tan\beta \lesssim 30$ for $M_A = [110, 150]$ GeV

* evaluated in $A \to \tau^+\tau^-$ channel.



Neutral MSSM Higgs Bosons at the LHC



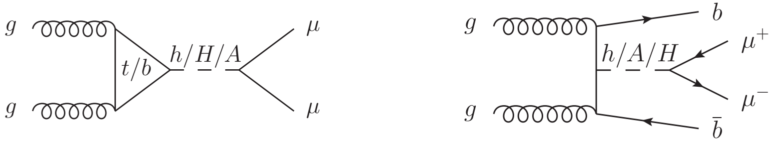


Production at the LHC:

* Direct production dominant for $\tan\beta \lesssim 10$.
* Associated production with b-quarks dominant for $\tan\beta \gtrsim 10$).
* $\sigma_{pp\to A}$ grows with $\tan\beta$ and falls with M_A.

Relevant Decay Channels:

* $h/A/H \to b\bar{b}$: Largest branching fraction ($\sim 90\%$); large QCD background.
* $h/A/H \to \tau^+\tau^-$: Branching fraction $\sim 10\%$; neutrino contribution in final state.
* $h/A/H \to \mu^+\mu^-$: Low branching fraction (0.04%); very clean signature; highest mass resolution $\to$ **crucial for Higgs mass measurement.**



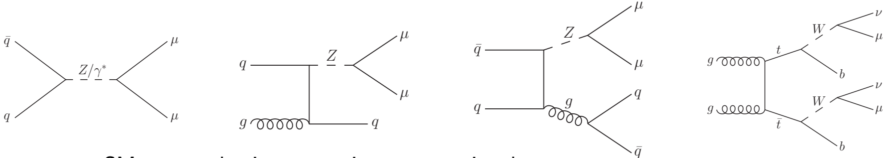
Characterisic signature of the $h/A/H \to \mu^+\mu^-$ Decay:

- Two high p_T muons (depending on M_A),
- having opposite charge and
- isolated tracks.

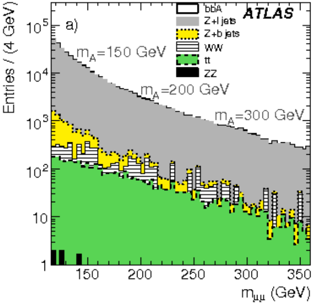
Signal signature in associated b-jet production:

- $h/A/H \to \mu^+\mu^-$ decay signature as above,
- additionally one or two low-p_T b-jets.

Background Processes



- SM process having same signature as signal process:
  - $Z \to \mu^+\mu^-$ produced in Drell-Yan or associated jet production.
  - $t\bar{t} \to \mu\nu b + \mu\nu b$.
  - $Z \to \tau^+\tau^-$ with leptonic $\tau \to \mu$ decays.
  - misidentified final states from or diboson or QCD dijet events.
- Dominant processes: Z and $t\bar{t}$ (exceed signal by $\approx 4 - 5$ orders of magnitude).



Event Selection

Preselection

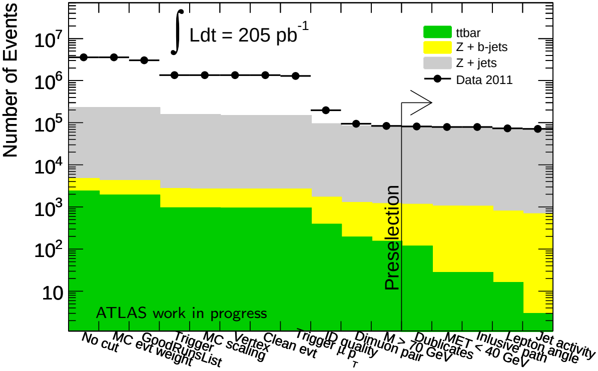
- Event is in GoodRunsList (requiring ATLAS detector fully operational).
- Event passed high-p_T single muon trigger EF_mu20.
- At least one primary vertex with at least 5 tracks.
- Trigger muon has $p_T > 20$ GeV.
- Muon pair formed of highest p_T leptons with opposite charge and $p_T > 20$ GeV.
- Cosmic/Pileup rejection: $z_0 < 10$, $d_0/d_0^{error} < 10$ (associated ID track).
- $M_{\mu^+\mu^-} > 70$ GeV.

Inclusive Final State Selection

- $E_T^{miss} < 40$ GeV (RefFinalEM)
- $|\sin\Delta\phi_{\mu\mu}| < 0.75$
- $\sum p_T^{jet} < 90$ GeV

Inclusive Analysis Cutflow

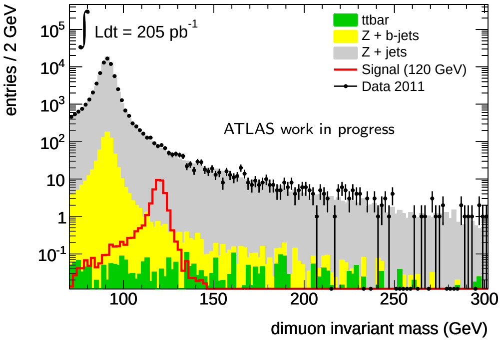
Cut Evolution in Inclusive Analysis



- Monte Carlo content consistent with data after Preselection
  $\rightarrow$ contributions from QCD and diboson event neglected.
- Fraction of events passing all cuts: $\sim 2 \cdot 10^{-3}$.

The Inclusive Final State

Invariant Mass Distribution of Selected Events



- Tail of Z resonance provides overwhelming background even for high masses.
- $t\bar{t}$ contributes with continuous invariant mass distribution.

Expected and observed events in mass window $[108, 132]$ GeV:

M_A (GeV)		expected					observed
		signal($\tan\beta = 40$)	Z + jets	Z + b-jets	$t\bar{t}$	SM Total	Data 2011
120	± 12	34.7[2]	973[5]	7.9[5]	0.46[5]	982[5]	1002

Estimation of the Background

- An estimate of the background is a crucial quantity for evaluating the discovery potential or exclusion limits.
- To reduce impact of systematic uncertainties it's desirable to estimate the background from data.

How to Estimate the Background from Data:

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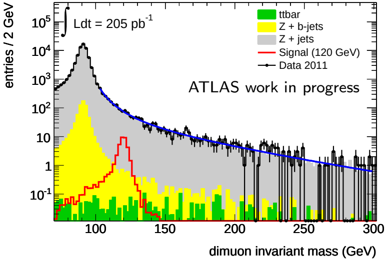
How to Estimate the Background from Data:

- Fit to the side bands of signal region in $\mu^+\mu^-$-distribution.
  $\Rightarrow$ requires certain amount of statistics.

Dimuon Invariant Mass



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- Fit to the side bands of signal region in $\mu^+\mu^-$-distribution.

- Use of signal-free control samples from e^+e^- final state.
  $\Rightarrow$ requires good understanding of differences in electron and muon reconstruction.

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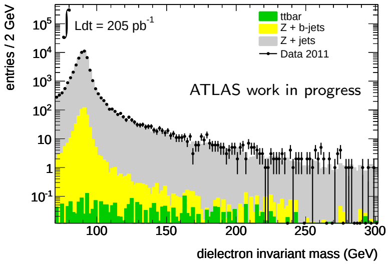

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How to Estimate the Background from Data:

- Fit to the side bands of signal region in $\mu^+\mu^-$-distribution.
- Use of signal-free control samples from e^+e^- final state.
- Combination of both methods: Use normalization parameters from side band fit and shape parameters from control sample.

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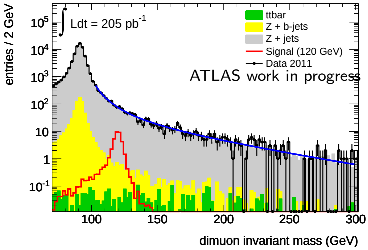

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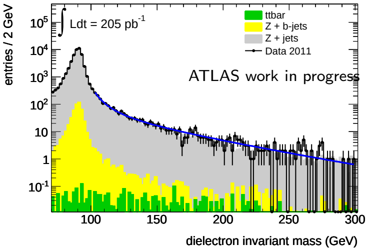


Improvements to the Event Selection

Sensitivity is increased by separating the events into two complimentary final states:

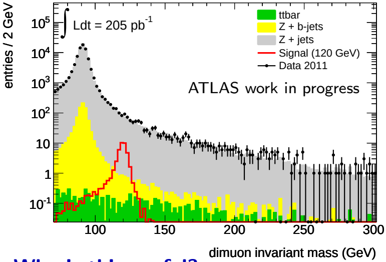
- Event preselection.
- $E_T^{miss} < 40$ GeV (RefFinalEM)

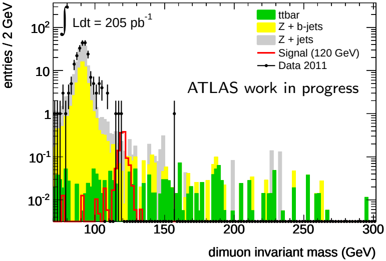
"No b-jet final state"

- No reconstructed b-jets.

"b-jet final state"

- At least one b-jet.
- $|\sin \Delta\phi_{\mu\mu}| < 0.75$
- $\sum p_T^{jet} < 90$ GeV





Why is this useful?

- By requiring a b-jet a huge fraction of $Z+$ light jet background is rejected.
- Due to very high rejection b-jet selection opens up for $0.5 - 1$ fb^{-1}.
- Possiblity to combine results of both final states is kept in mind.

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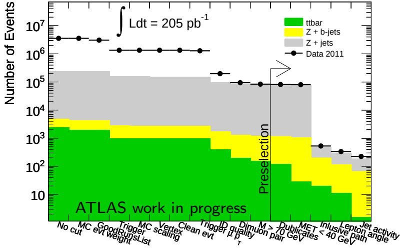

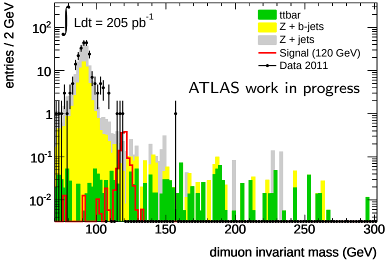

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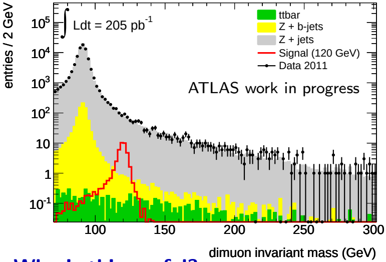

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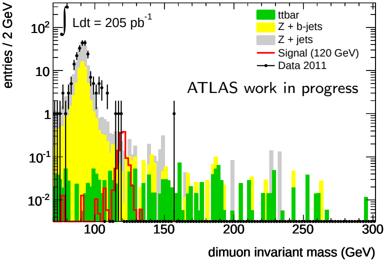

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Summary and Outlook

- This year ATLAS will become sensitive to various New Physics processes.
- Also the $h/A/H \rightarrow \mu^+\mu^-$ channel will open up, which
  - can contribute to exclusion limits set by $h/A/H \rightarrow \tau^+\tau^-$ and
  - is essential for a potential Higgs mass measurement.
- Control of the background is crucial $\rightarrow$ independent methods are pursued.
- By having an integrated luminosity > 500 pb^{-1} the event selection can be tightened
  $\Rightarrow$ clear improvement in sensitivity is expected.

Outlook

Full analysis including exclusion limits is planed to go into a summer conference note by the end of July.