Prospects for Standard Model Higgs Physics with the ATLAS Detector at the LHC

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Content

1. SM Higgs boson production
2. Decay channels
   - H $\rightarrow\ \gamma\gamma$
   - (VBF) H $\rightarrow\ \tau\tau$
   - H $\rightarrow$ ZZ$^{(*)}$ $\rightarrow$ 4l
   - H $\rightarrow$ WW $\rightarrow$ $l\nu l\nu$

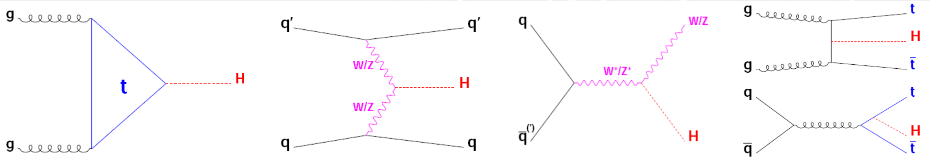
Introduction

- LHC is designed to run at a record center-of-mass energy of 14TeV
- But... First physics run will be at 10TeV (or less), with an expected integrated luminosity of about 200 pb^{-1}
- LHC detectors are getting ready to face any possible scenario:

- Higgs physics at the LHC with early data :
    - The WW channel is one of the most promising
    - Exclusion of $N\times$ the SM Cross Section for high masses can be achievable, using the 4l channel in the high mass range, and $\gamma\gamma$ for light masses
    - But the most important studies will be related with background normalizations and data driven extraction methods.

† In this talk: We will show ATLAS studies done at 14TeV in the $\gamma\gamma$ and $\tau\tau$ decay channels. Also some **preliminary** estimations on the impact of running at 10 TeV in the ZZ and WW channels, where I have been involved.

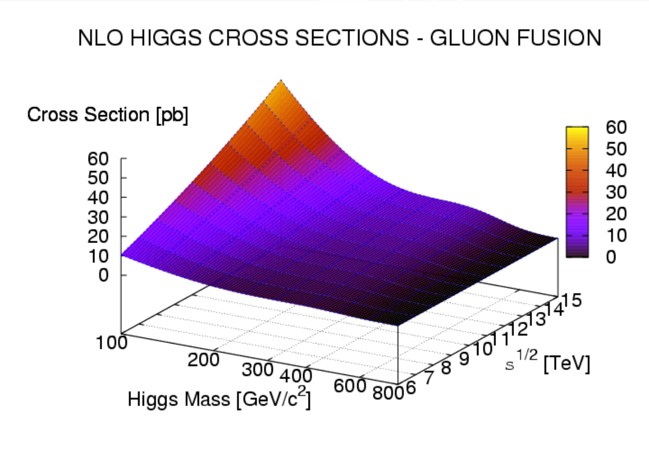
SM Higgs Production Processes



- gluon-gluon fusion is the dominant production process for a SM Higgs
- Vector Boson Fusion signatures can be relevant for some Higgs decay modes
- Associated productions become relevant in the case of a low m_H

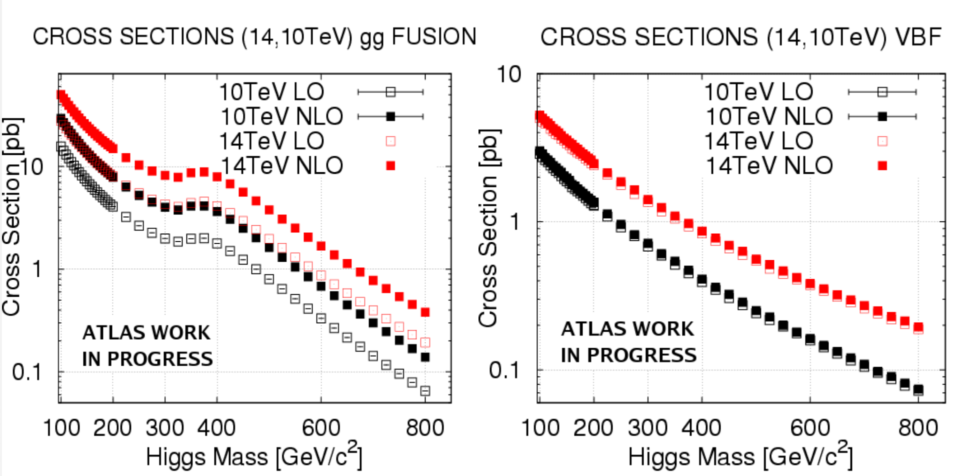
- Cross-section estimates are being updated. Trying to converge using high order calculations (NNLO, NNLL), electroweak corrections, and the most recent PDFs

Cross Sections (HIGLU @ NLO) — PDF:CTEQ6



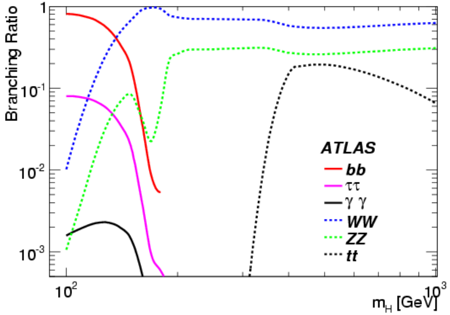
M_{uds} (MeV)	190	M_c (GeV)	1.4	M_b (GeV)	4.60	M_t (GeV)	172	Λ^{NLO}_{QDC} (MeV)	226
M_Z (GeV)	91.187	M_W (GeV)	80.41	G_F	$1{,}16639 \times 10^{-5}$	N_F	5	$\alpha_s^{NLO}(M_Z)$	0.118

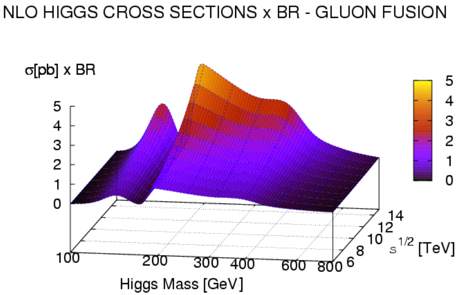
Cross Sections - Gluon Gluon Fusion and VBF



Calculations done with HIGLU and VV2H
- [Software → Michael Spira (PSI)]

Branching Ratios





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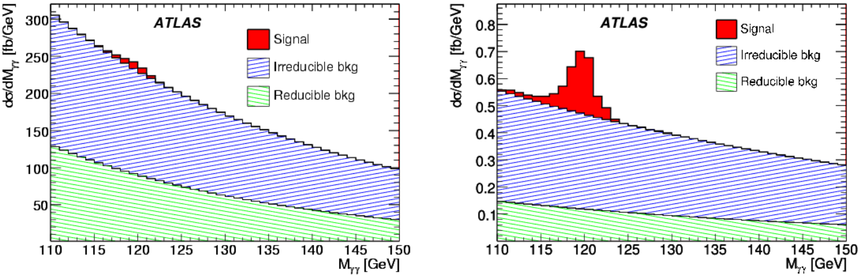
$H \rightarrow \gamma\gamma$ ($\sqrt{s} = 14$TeV)

- **Inclusive diphoton (gluon-gluon and VBF):**
  zero, one and 2 jets
- Also:
  $\gamma\gamma$ plus E_T^{miss} and an isolated lepton (WH and $t\bar{t}$H production)
  "Good" leptons coming from W decays
  $\gamma\gamma$ plus E_T^{miss} and no leptons (ZH $\rightarrow \nu\nu\gamma\gamma$)
  Large Missing energy, no converted photons (80GeV)

Inclusive

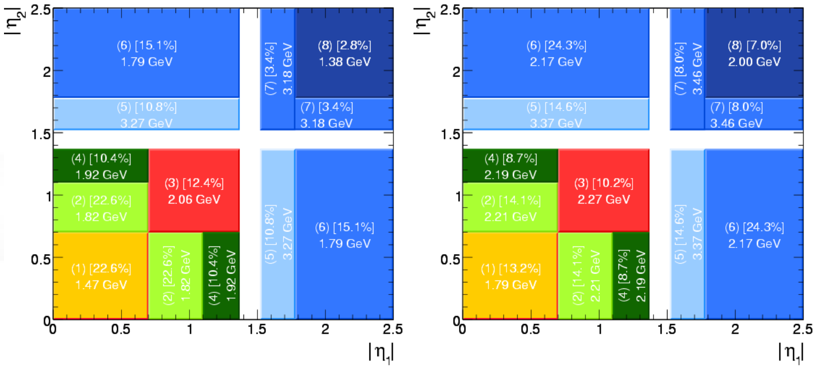
2 jets



Regions $\rightarrow$ Different photon Resolution, H $\rightarrow \gamma\gamma$

Regions of photon pseudo-rapidities

unconverted — atleast one converted photon



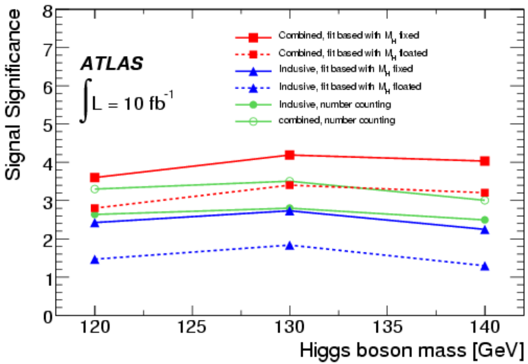
To simplify the likelihood model: 3 categories are defined:

"good":(1) and (8) "medium": (2)(3)(4) and (6) "bad" (5) and (7)

Expected cross sections and significance, H → $\gamma\gamma$

Cross Sections in fb

m_H	Inclusive S	Inclusive B	$H+1$jet S	$H+1$jet B	$H+2$jets S	$H+2$jets B	$H+E_T^{miss}+\ell$ S	$H+E_T^{miss}+\ell$ B	$H+E_T^{miss}$ S	$H+E_T^{miss}$ B
120	25.4	947	4.0	49	0.97	1.95	0.134	0.077	0.075	0.037
130	24.1	755	4.3	47	0.96	1.72	0.112	0.076	0.063	0.037
140	19.3	610	3.9	46	0.81	1.72	0.079	0.076	0.045	0.036



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VBF H $\rightarrow \tau\tau$ ($\sqrt{s} = 14$TeV), Selection:

Complete studies on leptonic and semi-leptonic tau decays.
(Full hadronic channel: effort ongoing)

EVENT SELECTION for *ll* :

- Exacly two leptons with opposite charge
- $E_T^{miss} > 40$GeV
- Collinear approximation
- b-jet veto
- Taging of VBF jets ($\Delta\eta_{jj} >$4.4 and $m_{jj} > 700$ GeV)
- Central jet veto ($p_T > 20$ GeV)
- Mass window

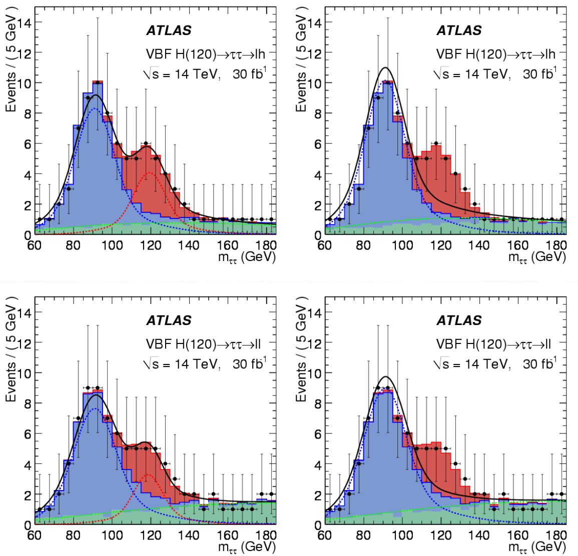
EVENT SELECTION for *lh* :

† Similar as *ll* but:

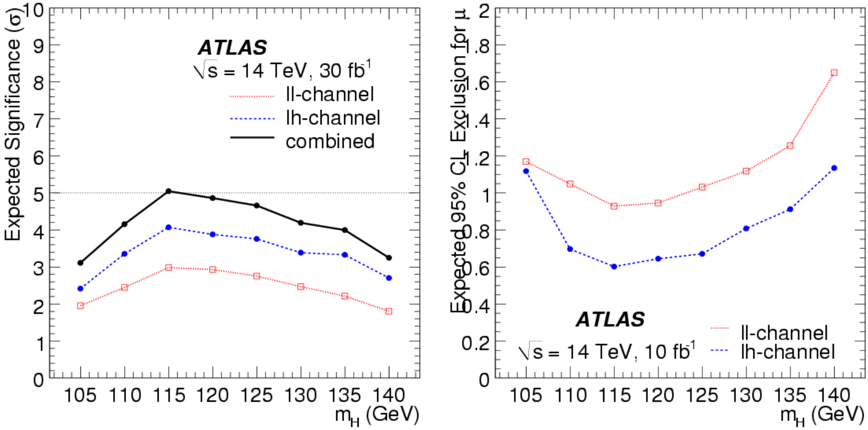
- 2 or more lepton veto
- At least one identified hadronic τ
- $E_T^{miss} > 30$GeV
- Collinear approximation (with asymmetric upper bounds)
- Transverse mass < 30 GeV
- No b-jet veto

lh and *ll*, Signal+Background and Background only

- Stacked Histograms
  lh and *ll* channels
  for S+B and B only
  Signal, Reducible
  and Irreducible
  Backgrounds
- m_H = 120 GeV
- Luminosity 30 fb^{-1}
- Control samples are fit simultaneously in order to constraint background shapes



Significance and Exclusion, VBF $H \to \tau\tau$



Signal significance and exclusion limit (95 %CL). Background uncertainties are incorporated by utilizing the profile likelihood ratio, these results do not include the impact of pileup

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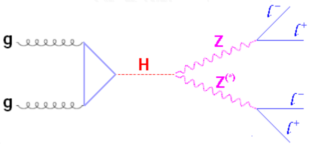
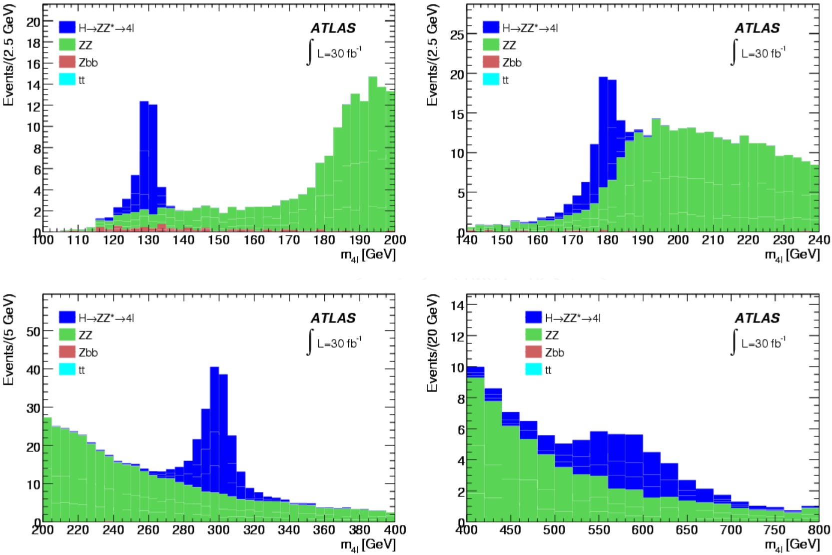
The “Golden” Channel



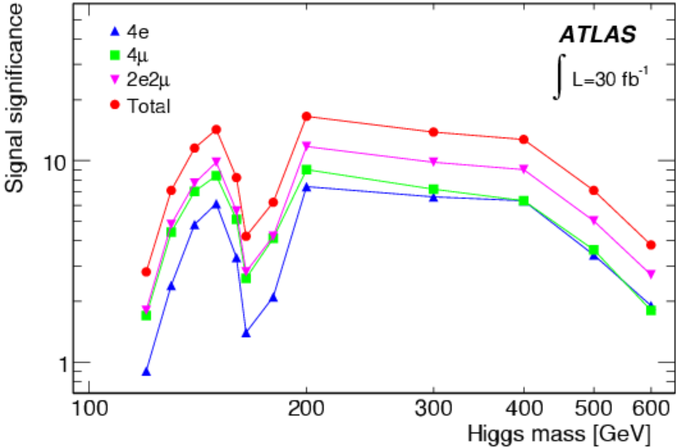
- It is one of the cleanest signatures
  - 4 Isolated leptons (μ,e) coming from Z decays (on shell or off shell in the case of low m_H)
  - Main discriminators: track and calorimeter isolation, impact parameter significance.

†Irreducible background: direct production of ZZ
†Reducible backgrounds: $t\bar{t}$, $Zb\bar{b}$, Z/γ+jets

The “Golden” Channel ($\sqrt{s} = 14$TeV)

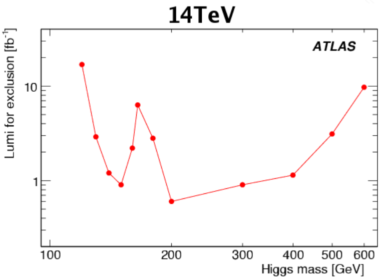


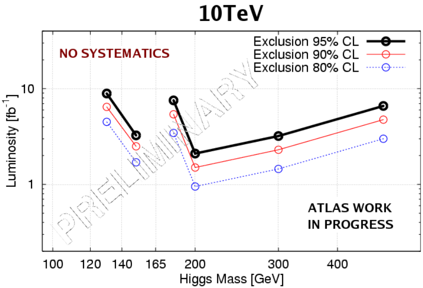
$H \rightarrow ZZ^{(*)} \rightarrow 4l$ ($\sqrt{s} = 14$TeV)



H → $ZZ^{(*)}$ → 4l, going from 14 to 10 TeV

10TeV estimations are based on an event-by-event re-weight procedure using 14TeV MC samples





This comparison is only for raw illustrative purposes, in **this** 10TeV study no systematic uncertainties were taken into account.

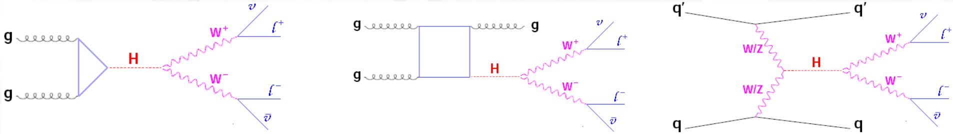
For 10TeV, the Collaboration has many studies ongoing on background normalizations (reducible and irreducible), as well as on selection optimization

Content

Higgs to WW

Haijun Yang covered this channel in Today's session, here we point out some highlights of the strategy with early data

- This analysis is usually divided in different analysis for different jet multiplicity:



- Then systematic uncertainties can be treated differently
- Some of the features of this channel:
  - Missing energy as part of the signature.
  - Jet discriminators are needed
  - Backgrounds with cross sections many orders of magnitude bigger than signal need to be reduced.
  - Will be affected by large theoretical and detector uncertainties.
  - Systematics MUST be under control

H$\to$ WW, and strategy for early data

- A cut-based analysis was proposed for the early data
  Have in mind that **statistical uncertainties** are going to be dominant.
- The relevant backgrounds for this analysis:
  - QCD WW (dominant in 0 and 1 jet)
  - ttbar and single top (dominant in 2 jets)
  - WZ
  - Z + jets (same flavor channels)
  - W + jets
    (cross sections many orders of magnitude bigger than Higgs production)
  - QCD Dijets
  - bbbar (some predictions of underestimation and an enormous cross section)

- For different jet multiplicities the impact of the different backgrounds is different

H$\longrightarrow$ WW, Selection

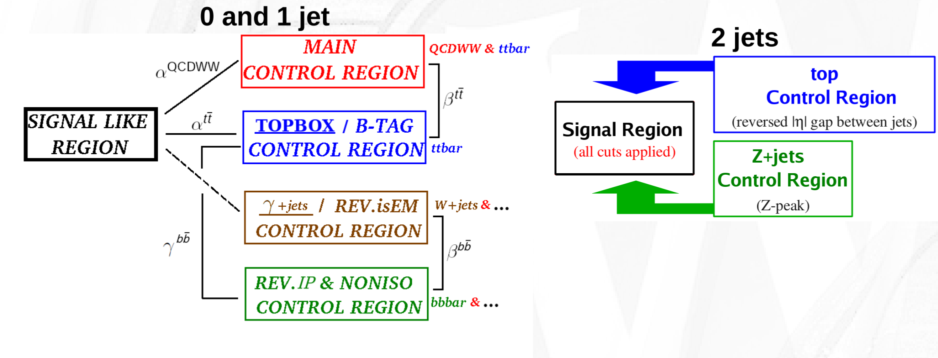
- The two Leptons, coming from W decays:
  - Pt $>$ 15GeV
  - Electrons should pass all the quality criteria based on shower shape identification
  - Muons should leave traces in both: the inner detectors and in the muon spectrometers
  - Well isolated (“track” and caloremeter)
  - Small Impact Parameter

  The aim is to reduce the impact of fake lepton reconstruction
- Missing Energy signature left by the neutrinos can be used as discriminator
- Successive requirements in the jet selection and topological selections help us to reduce backgrounds like ttbar or QCDWW

$H\rightarrow$ WW, Control Regions

In order to estimate the impact of the main backgrounds, different control regions can be defined reversing or changing some cuts from the signal-like region.

$$\sigma_{CR}^{data} \rightarrow \sigma_{SR}^{bkgr} = \sigma_{CR}^{data} \cdot \alpha_{SR/CR}^{MC}$$

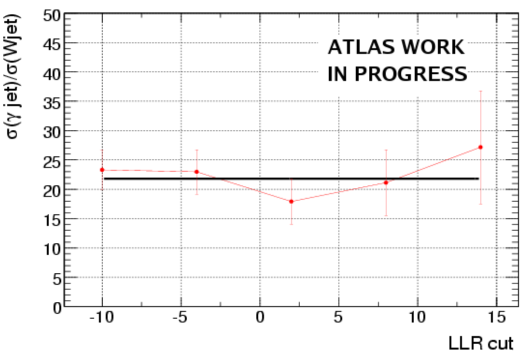


Different jet multiplicity $\rightarrow$ different systematic errors on the extrapolation ratios

W+jets Normalization

Among different methods to estimate the contribution of W+jets, here:

- Based on a control sample with a very tight photon and an electron candidate
- Ratio of γ+jets to W+jets is approximately constant w.r.t. electron cuts
  Deviation from constant is taken as systematic → 20 %
  Error from MC statistics is not trivial

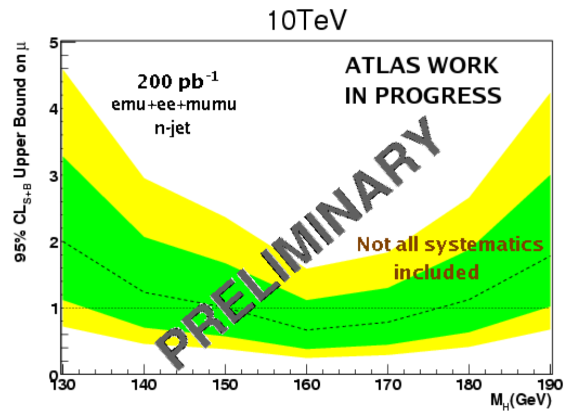


- Some other approches that might apply for higher luminosities have also been studied [1]

[1] Y. Fang: → subtraction (using different electron ID)

H$\to$ WW, 95 % CL Exclusion @ 200 pb^{-1}

Combination for the three different flavor channels: $e\mu$, ee and $\mu\mu$, for 0,1 and 2 jet bins. The frequentist approach, (profile likelihood ratio) is used to obtain this limit



- This is a preliminary result, studies are on going to make sure all the systematics under control
- No uncertainties on signal normalization are considered!

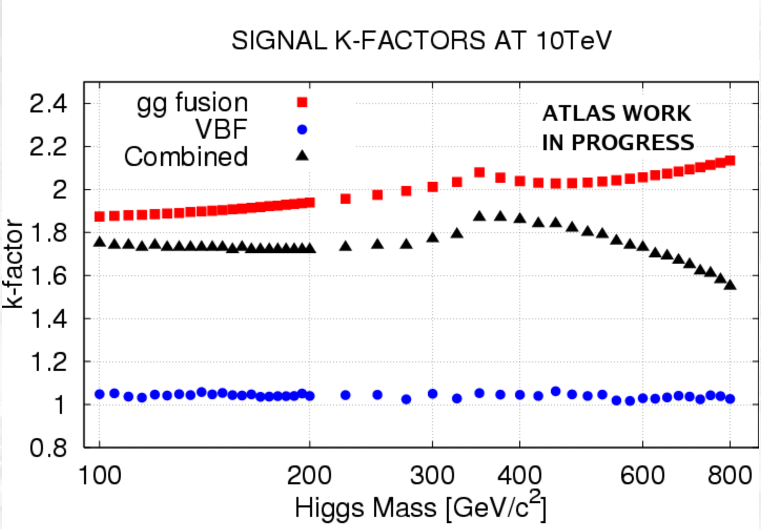
Summary

- Some estimate of the cross sections for different center-of-mass energies were presented
- A brief description of the studies done by the ATLAS Collaboration on different decay channels of the SM Higgs was shown
- Some emphasis was placed on various efforts to estimate the impact of running at 10TeV instead of 14TeV:
  - For the 4l channel, a simple study for comparison was shown, where a reweighting (event-by-event) is implemented, and uncertainties are not considered
  - In the case of WW$\rightarrow$ lνlν, a cut-based analysis aimed for early-data was performed, background extraction using control samples is crucial to understand the impact of systematics.

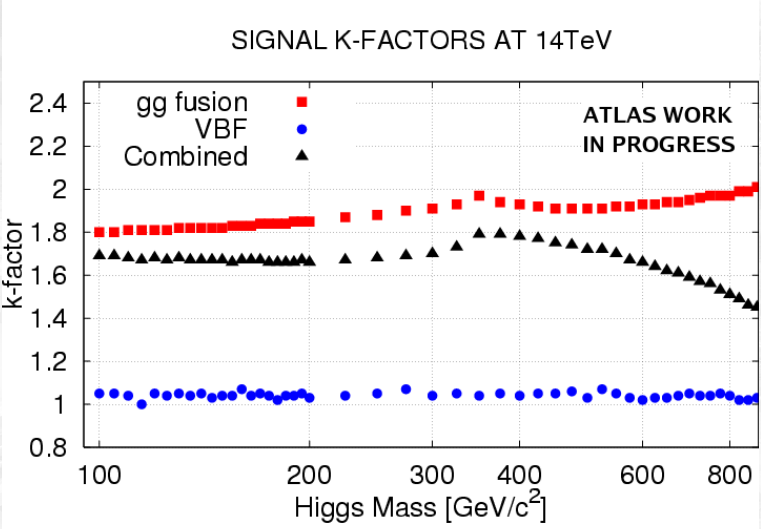
THANKS !!!

BACK UP SLIDES !!!

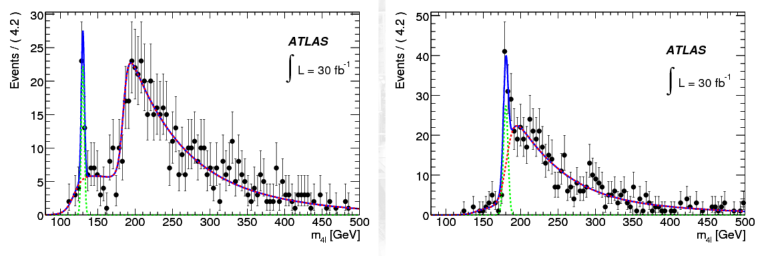
k-factors


SIGNAL K-FACTORS AT 10TeV
gg fusion
VBF
Combined
ATLAS WORK
IN PROGRESS
k-factor
2.4
2.2
2
1.8
1.6
1.4
1.2
1
0.8
100
200
300
400
600
800
Higgs Mass [GeV/c^2]

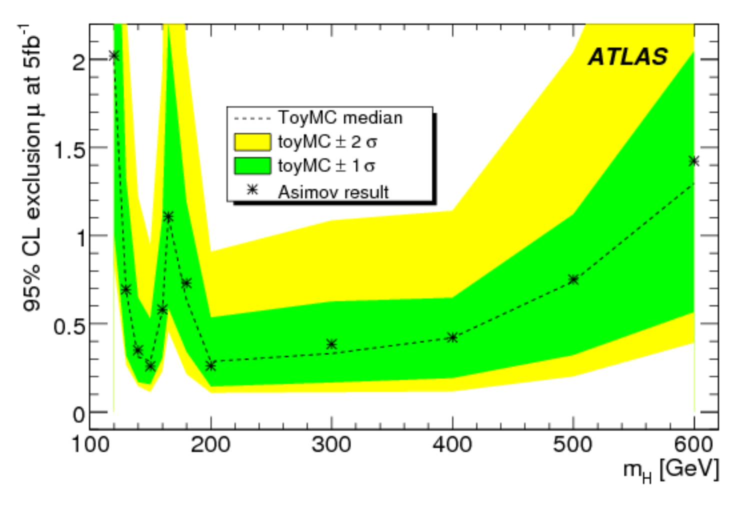
k-factors


SIGNAL K-FACTORS AT 14TeV
gg fusion
VBF
Combined
ATLAS WORK
IN PROGRESS
k-factor
2.4
2.2
2
1.8
1.6
1.4
1.2
1
0.8
100
200
300
400
600
800
Higgs Mass [GeV/c2]

H $\rightarrow$ ZZ $\rightarrow$ 4l



$H \to ZZ \to 4l$


ATLAS
ToyMC median
toyMC ± 2 σ
toyMC ± 1 σ
Asimov result
95% CL exclusion μ at 5fb⁻¹
0
0.5
1
1.5
2
100
200
300
400
500
600
m_H [GeV]

H → WW discovery potential