Prospects for Higgs boson searches with ATLAS Part I: Higgs decays to gauge bosons

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BNL

On the behalf of the ATLAS Collaboration

Outline

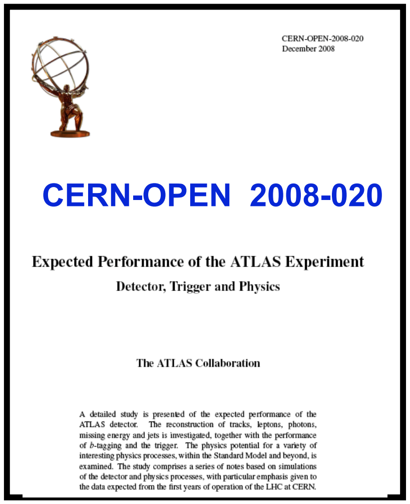
- SM Boson Higgs decays to gauge bosons
  - $H \rightarrow \gamma\gamma$
  - $H \rightarrow ZZ$
  - $H \rightarrow WW$
- Charged Higgs
  - $H^{+} \rightarrow \tau\nu$

See the talk by M. Schumacher in the same workshop for the Higgs boson decays to fermions

Improvement in Higgs Studies at the LHC

- Many studies have meanwhile been performed using detailed GEANT simulations of the detectors
  - "Expected Performance of the ATLAS Experiment" , Dec 2008, arxiv:09010512

- New (N)NLO Monte Carlos (also for backgrounds)
  - MCFM Monte Carlo, J. Campbell and K. Ellis, http://mcfm.fnal.gov
  - MC@NLO Monte Carlo, S.Frixione and B. Webber, wwwweb.phy.cam.ar.uk/theory/
  - T. Figy, C. Oleari and D. Zeppenfeld, Phys. Rev. D68, 073005 (2003)
  - E.L.Berger and J. Campbell, Phys. Rev. D70, 073011 (2004)
  - C. Anastasiou, K. Melnikov and F. Petriello, hep-ph/0409088 and hep-ph/0501130
  - …..


CERN-OPEN-2008-020
December 2008

CERN-OPEN 2008-020

Expected Performance of the ATLAS Experiment
Detector, Trigger and Physics

The ATLAS Collaboration

A detailed study is presented of the expected performance of the ATLAS detector. The reconstruction of tracks, leptons, photons, missing energy and jets is investigated, together with the performance of *b*-tagging and the trigger. The physics potential for a variety of interesting physics processes, within the Standard Model and beyond, is examined. The study comprises a series of notes based on simulations of the detector and physics processes, with particular emphasis given to the data expected from the first years of operation of the LHC at CERN.

- New approaches to match parton showers and matrix elements
  - ALPGEN Monte Carlo + MLM matching, M. Mangano et al.
  - SHERPA Monte Carlo, F. Krauss et al.
  - …

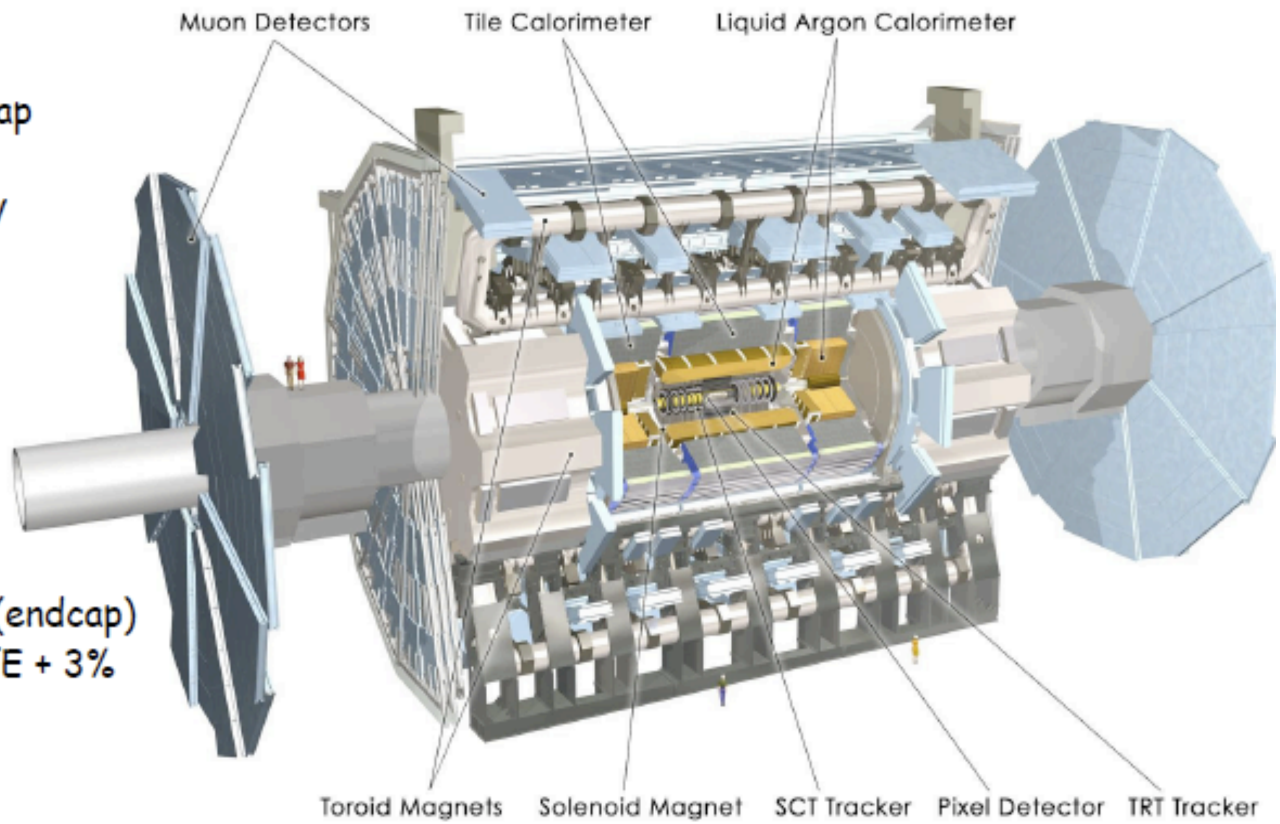
  Tevatron data are extremely valuable for validation, work has started

- More detailed, better understood reconstruction methods

  (partially based on test beam results,…)

ATLAS detector

Muon spectrometer:
- air-core toroids:
  0.5 T in barrel, 1 T in endcap
- momentum resolution:
  2% @ 50 GeV, 10% @ 1 TeV
  (combined ID+MS)



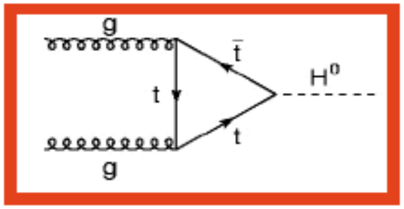
HCAL:
- Fe+scint (barrel), Cu+LAr (endcap)
- resolution $\sigma(E)/E \approx 50\%/\sqrt{E} + 3\%$
  (ECAL+HCAL, barrel part)

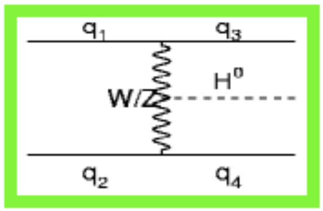
ECAL:
- Pb+LAr technology
- resolution $\sigma(E)/E \approx 10\%/\sqrt{E} + 0.7\%$

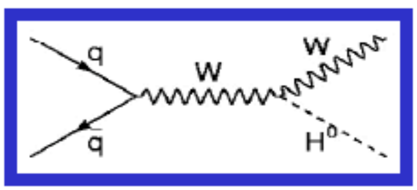
Tracker:
- Si pixels, Si strips, TRT inside 2 T solenoid
- resolution: $\sigma(p_T^{-1}) \approx 0.36 + 13/(p_T \cdot \sqrt{\sin\theta})$ [TeV^{-1}]

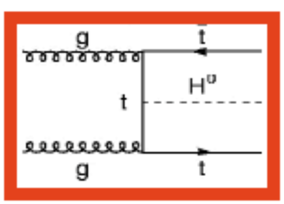
Further details in Ref:
G. Aad et al., JINST 3 (2008) S08003

Higgs Production at the LHC

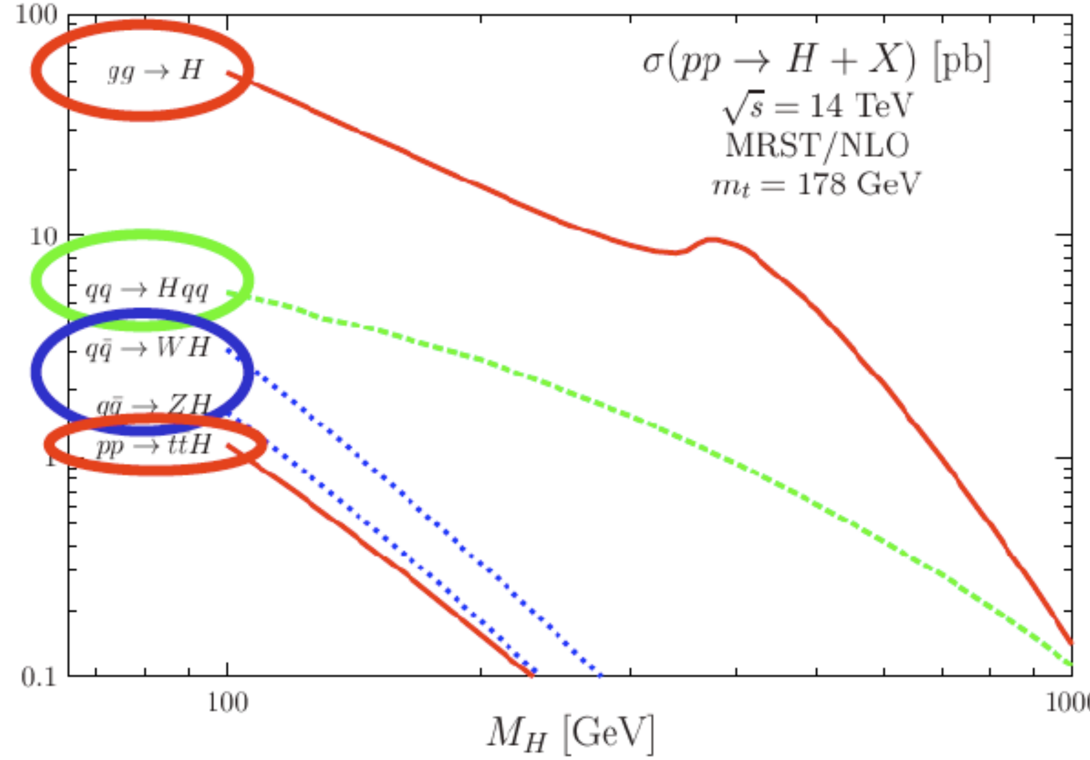








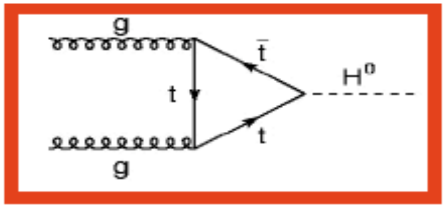
A.Djouadi Phys.Rept.457:1-216



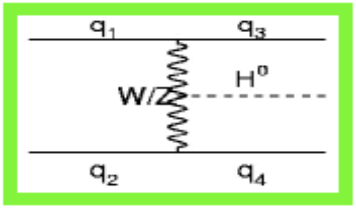
***gg fusion* process is the more abundant, followed by the *Vector Boson Fusion* process.**

See later for discussion on Higgs cross sections

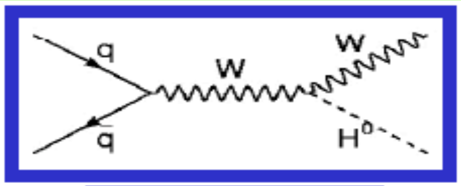
SM Higgs Decays at the LHC



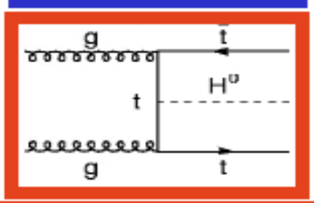
GF **H → WW, ZZ , γγ**



VBF **H → WW , γγ , ττ**

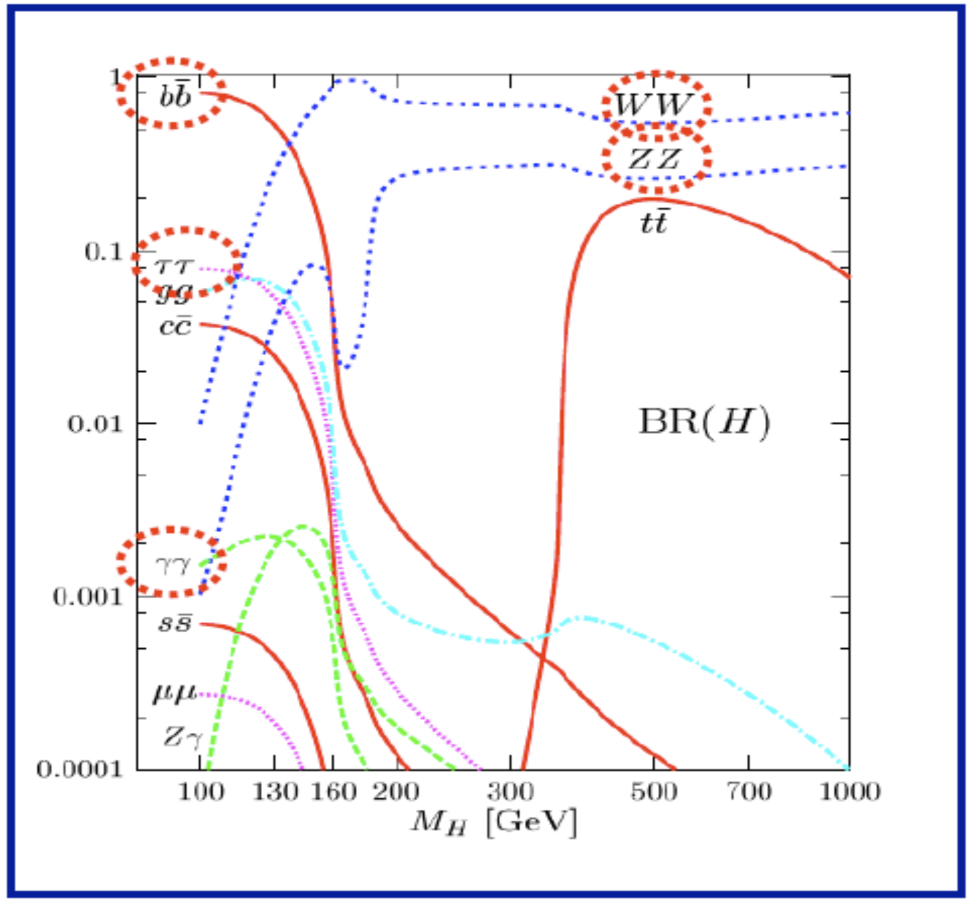


H → WW, γγ



H → WW, γγ, bb

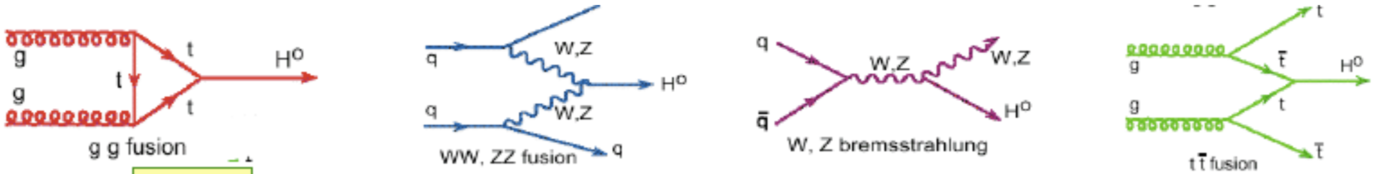
A. Djouadi, J. Kalinowski and M. Spira Comp. Phys. Comm 108 (1998) 56

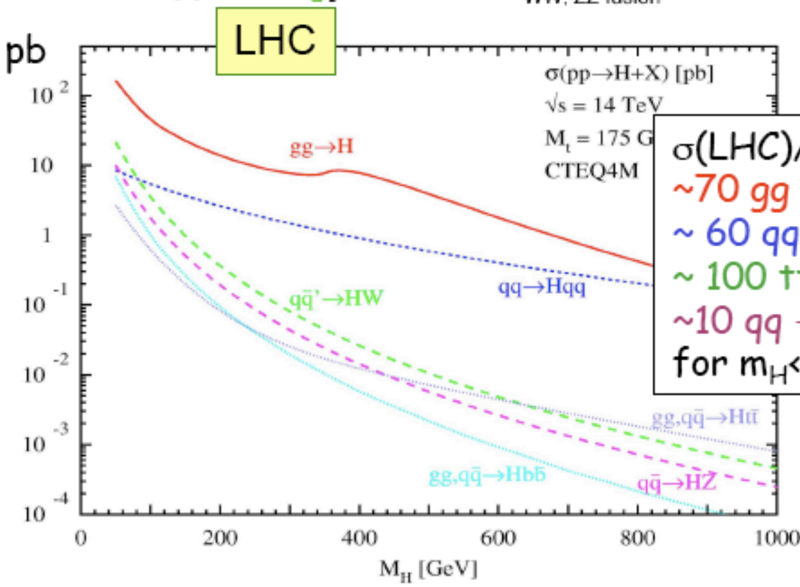


Many channels explored!

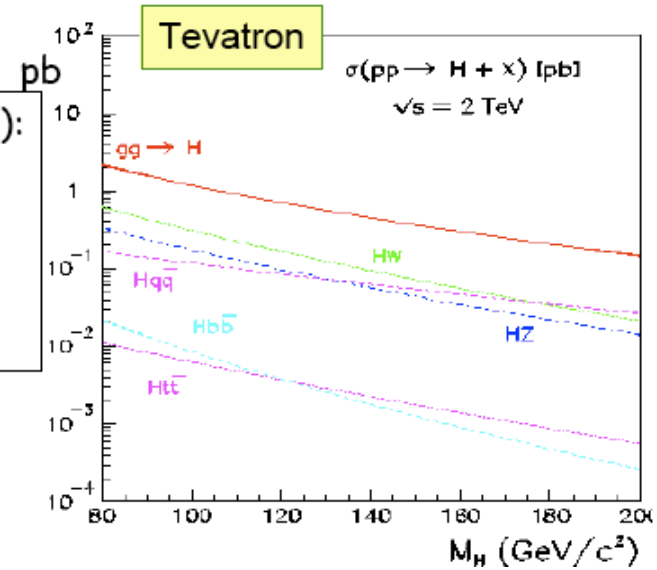
The whole mass range covered

Light Higgs Boson …





σ(LHC)/σ(Tevatron):
~70 gg → H
~ 60 qqH → qqH
~ 100 ttH
~10 qq →WH/ZH
for m_H<200 GeV



	Tevatron Main Search Channels	LHC Main Search Channels
m_H ~115 GeV	WH→ lνbb ZH → ννbb, llbb	H → γγ, qqH → qqττ, WH→lνbb ttH→ lνbbX
m_H ~ 160 GeV	H →WW → lνlν	H → WW→ lνlν,H→ZZ*→4l, qqH→ qqWW→ qqlνlν

Large backgrounds at the LHC

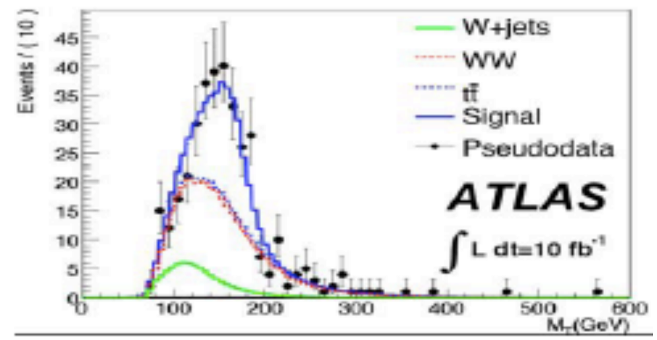
Cross-sections too small at the Tevatron

Early Data Analysis Preparation

- Getting ATLAS ready to read and analyze the data for detector commissioning and calibration, trigger commissioning, software and computing system commissioning with collisions are the highest priorities of ATLAS
- 900 GeV
  - We expect to see 900 GeV collisions before 7 TeV collisions - assuming 3 shifts of 10h each and DAQ efficiency of 50%, with 200 Hz event rate, we expect about 9M events on disk
  - Allows an early comparison between Monte Carlo and collision data – potentially useful for commissioning
- 7 TeV – Priority would be on SM
  - Minimum bias, Di-jet events, W, Z, Top, etc
- 100-200/pb, 7-10 TeV
  - SM WW, ZZ measurements. Exclusion limits in H → WW
  - Data driven background estimation methods
- Preparing tools to compute Higgs boson cross-sections and branching ratio as function of CM energy
- Preparing statistical tools for combined exclusion limits

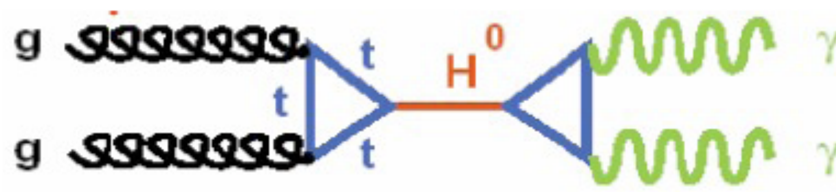
Data Driven Background Estimation

- Extraction of W+jets background in H→WW (→ll+MET) +nj channel
  - W+jets background from one genuine lepton and one fake lepton. It also has an intrinsic MET



  - Hard to estimate jet -> fake lepton contribution from MC. W+jets cross section has large theoretical uncertainties
  - Use data driven background estimation methods, some examples:
    - Extrapolation method from loose leptons using di-jet events (fakeable objects)
    - Based on γ+jets events
    - Subtraction method
    - Estimate of opposite sign contribution from same sign
    - Estimation of Z→ll background in H→WW (→ll+MET)+0j

Higgs → γγ



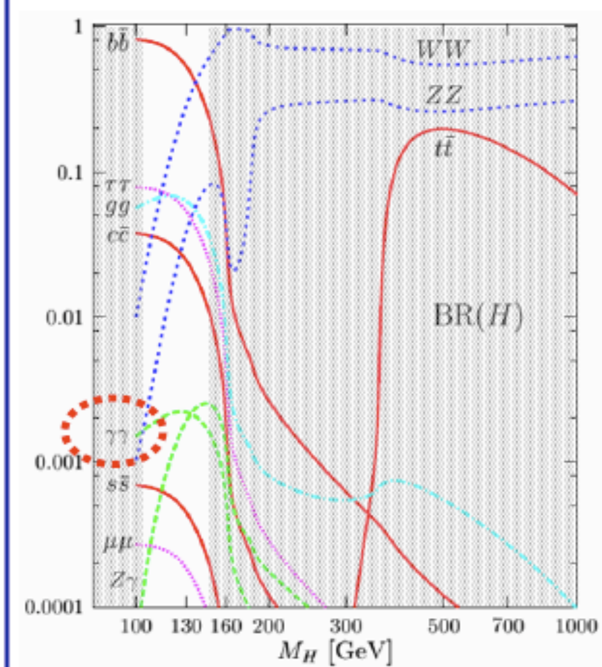
ATLAS

- ***Important channel in the low mass region.***
- ***It gives the best mass resolution thanks to excellent electromagnetic energy resolution***

SELECTION

- **Trigger**: at least 2 isolated photons, with $p_T > 20\ GeV/c$ each
  → $\varepsilon\,(respect\ to\ offline) = (93.6 \pm 0.4)\%$
- **Identification cut** exploiting the shower shape.
- **Fiducial cut**: $0 < |\eta| < 1.37$ & $1.52 < |\eta| < 2.37$.
- **Isolation cut**: $\Sigma p_T < 4\ GeV/c$, considering all tracks with $p_T > 1 GeV/c$ in a $\Delta R = 0.3$ cone around the electromagnetic cluster.
- **Momentum cut**: $p_T > 25 GeV/c$ and $p_T > 40 GeV/c$ for the two most energetic photons.

Selection efficiency:
$\varepsilon = 36.0\ \%$ (32.2% with pileup $10^{33} cm^{-2} s^{-1}$)



In a mass window M_H +/- $1.4\sigma\ GeV$:

Signal Process	Cross-section (fb)
$gg \to H$	21
VBF H	2.7
ttH	0.35
VH	1.3

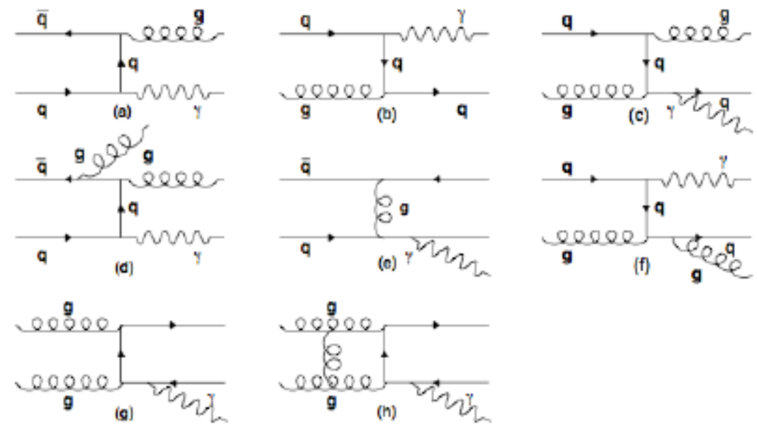
Higgs → γγ backgrounds

ATLAS

Within a mass window M_H +/- 1.4σ *GeV*:

Background Process	Cross-section (fb)
$\gamma\gamma$	562
Reducible γj	318
Reducible jj	49
Drell Yan	18

Example: γ-jet processes



- Background is evaluated with *NLO* simulations.
- ***It will be measured from data sidebands.***

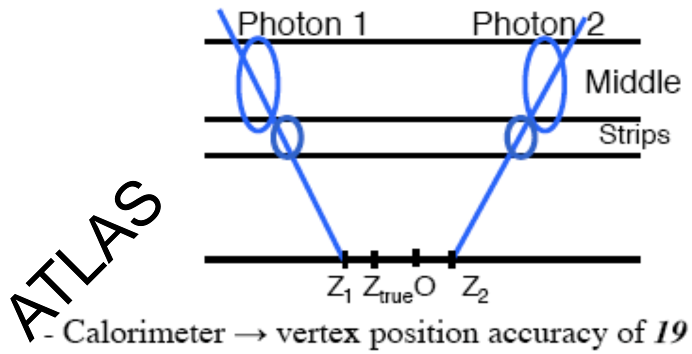
Strategy for jet rejection:

- *Longitudinal segmentation* of the calorimeter.
- Fine segmentation of the first layer (*η-strips*) => good π^0 rejection.
- *Isolation* of the *electromagnetic* cluster.
- *Isolation based on tracks* reconstructed by the inner detector.

Higgs → γγ reconstruction

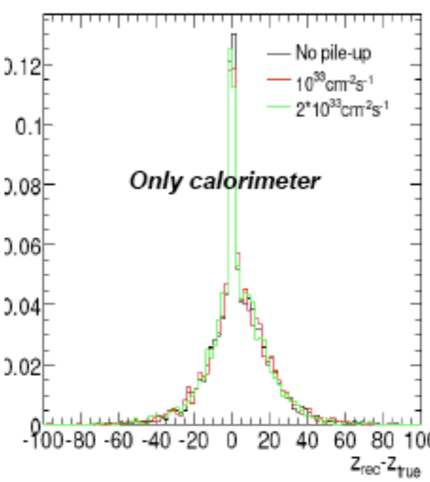
PRIMARY VERTEX

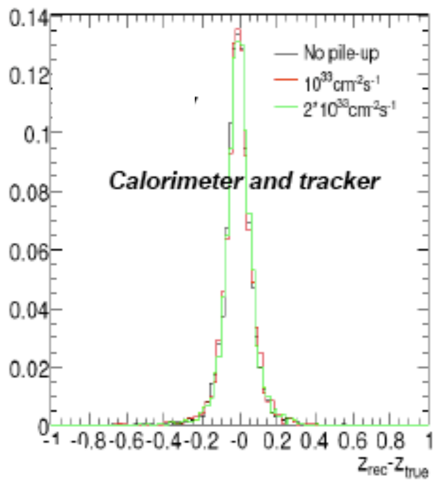
If the vertex is unknown, add 1.4 GeV to the mass resolution.
Combine calorimeter and tracker informations!



- Calorimeter → vertex position accuracy of ***19 mm***
- Combining with the tracker information → ***~0.1 mm***

Calorimeter information is useful in case of pile-up or events with low tracks multiplicity.

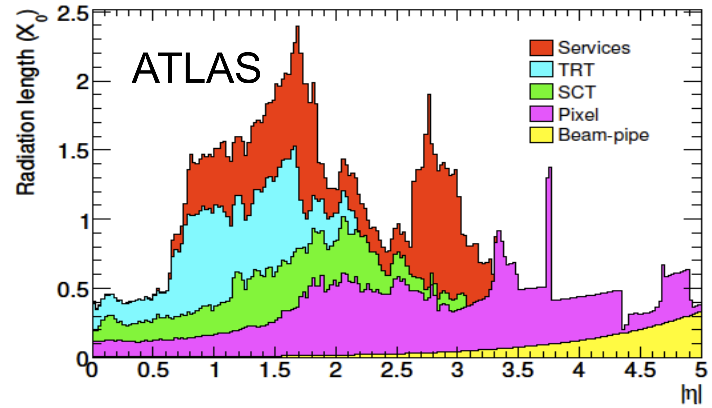


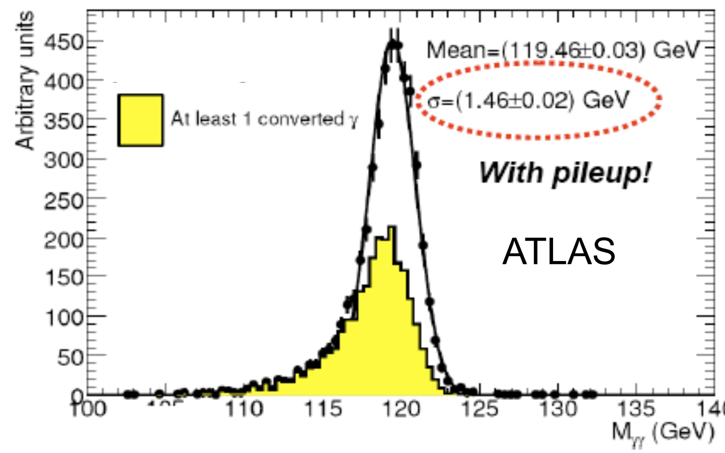


CONVERSIONS

~50% of the events with at least one converted γ !

- conversion vertex used in computation of the direction;
- used for gamma-jet background estimation.

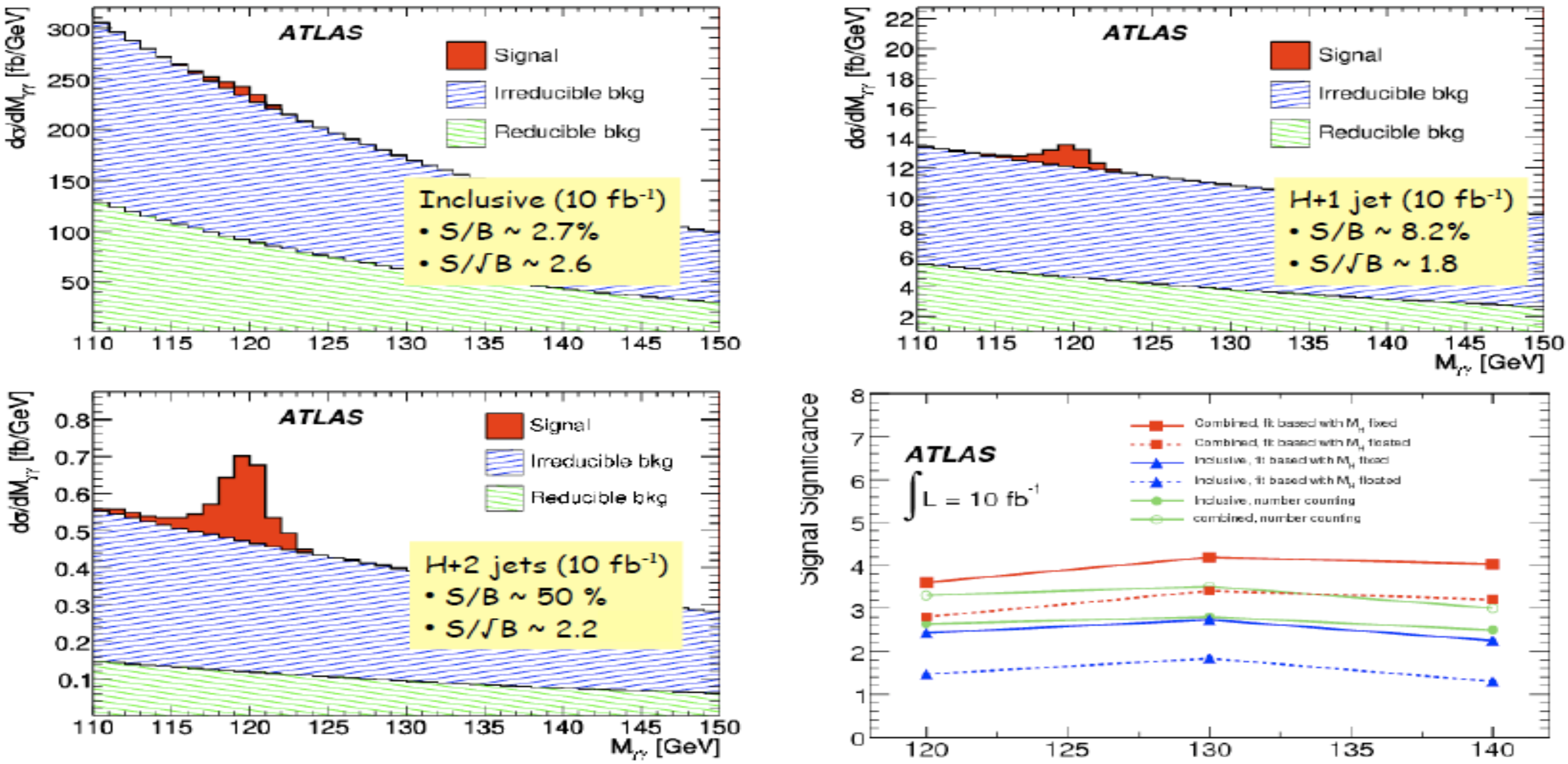




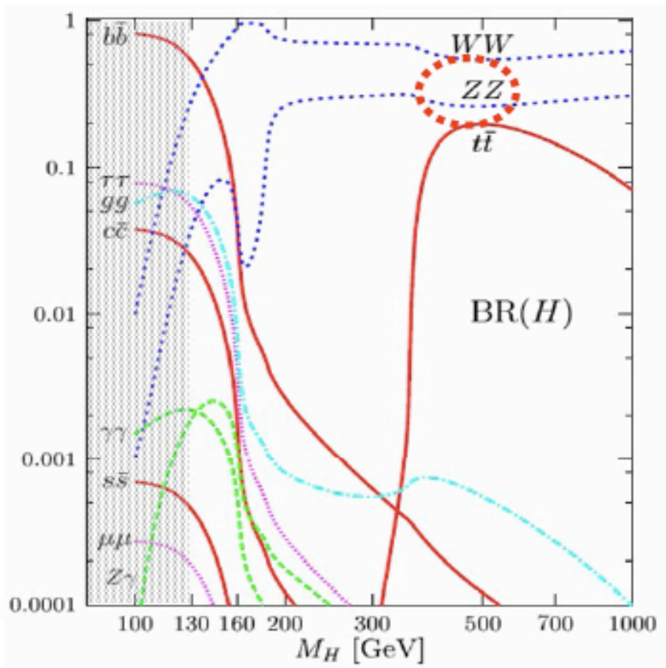
Higgs → γγ significance

New elements of the analyses:

- NLO calculations available
  (Binoth et al., DIPHOX, RESBOS)
- Realistic detector material
- More realistic K factors (for signal and background)
- Divide signal sample acc. to resolution functions



Higgs → ZZ(*) → 4l



SELECTION

- **Trigger**: - single isolated μ (e) with p_T>20 (25) GeV/c;
  - two μ (e) with p_T>10 (15) GeV/c.
- **Kinematic**: - 2 pairs of same flavor opposite charge lept.
  - p_T>7GeV (at least two with p_T>20GeV)
  - Lepton identification
  - $M_{ll2} > M_{34}$ for ZZ* and $|M_{ll2} - M_Z| < \Delta M_{12}$ for ZZ
- **Fiducial cut**: $|\eta| < 2.5$
- **Isolation cut**: - Calorimeter: $\Sigma E_T/p_T < 0.23$ ($\Delta R<0.2$)
  - tracker: $\Sigma p_T/p_T < 0.15$
- **Vertexing cut** on maximum lepton ***impact parameter***:

  $d_0/\sigma_{d0}<3.5$ (6.0) for μ (e)

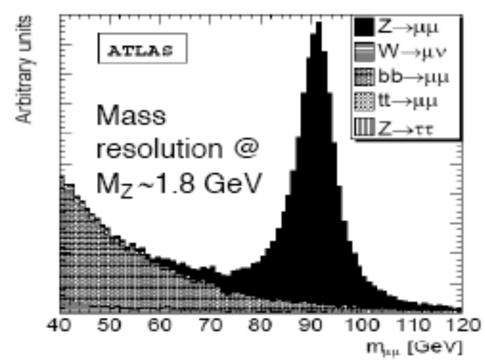
It is the "golden channel"!

- ***Observation of a clear peak on top of a smooth background!***
- ***Wide range of masses explored***

Background will be estimated in sidebands
→ low systematic uncertainties

•Look to the *Z* with first data to understand lepton reconstruction and detectors response.

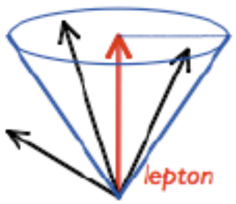
•*Z*→*ee* mass peak is affected by electron bremsstrahlung.



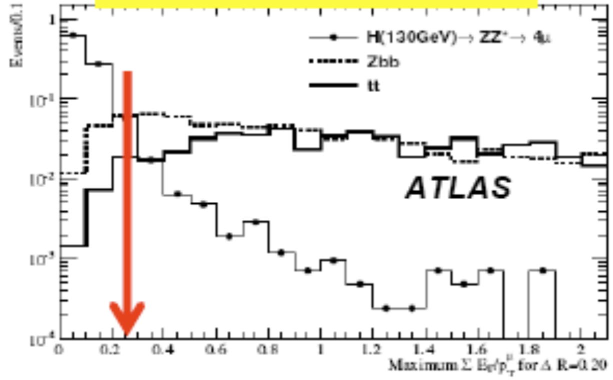
Higgs → ZZ* → 4l

Reducible backgrounds have activity around leptons from b-decay

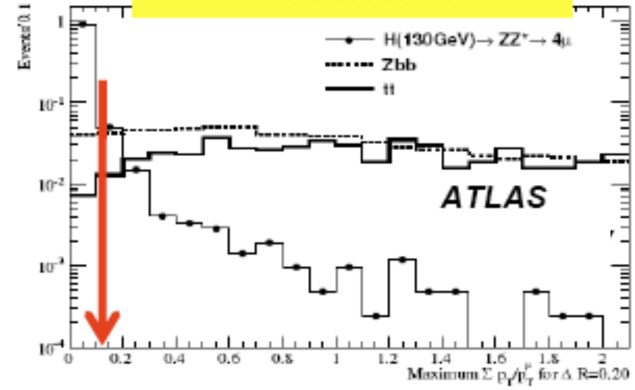
$$\Delta R = \sqrt{\Delta\eta^2 + \Delta\phi^2}$$



Calorimetric isolation

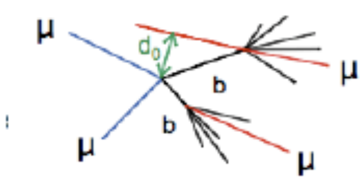


Track isolation

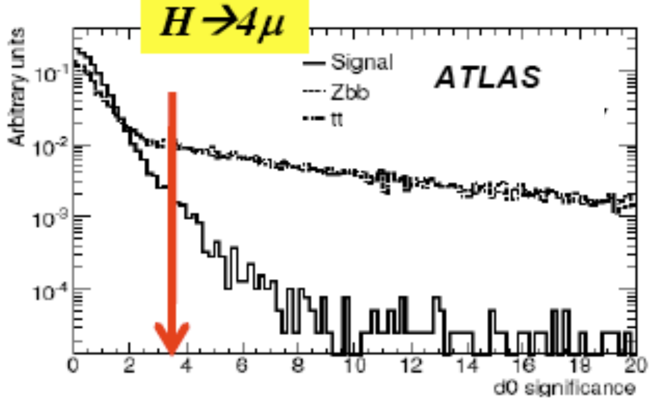


Normalized calorimetric and track isolation (ΔR=0.2) for the signal (m_H = 130) and the *Zbb* and tt backgrounds in the 4μ channel.

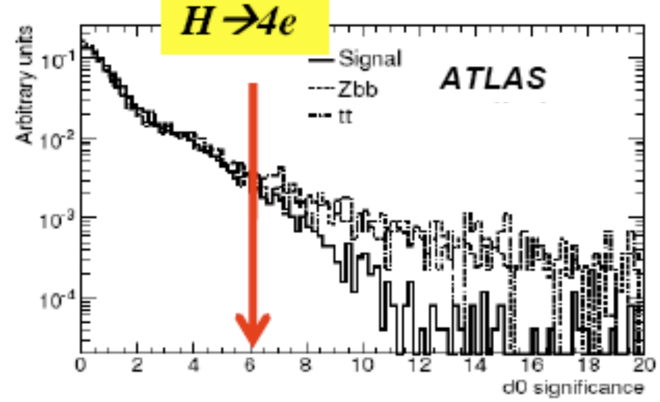
Lepton from b-quark decay do not point towards primary vertex



H→4μ

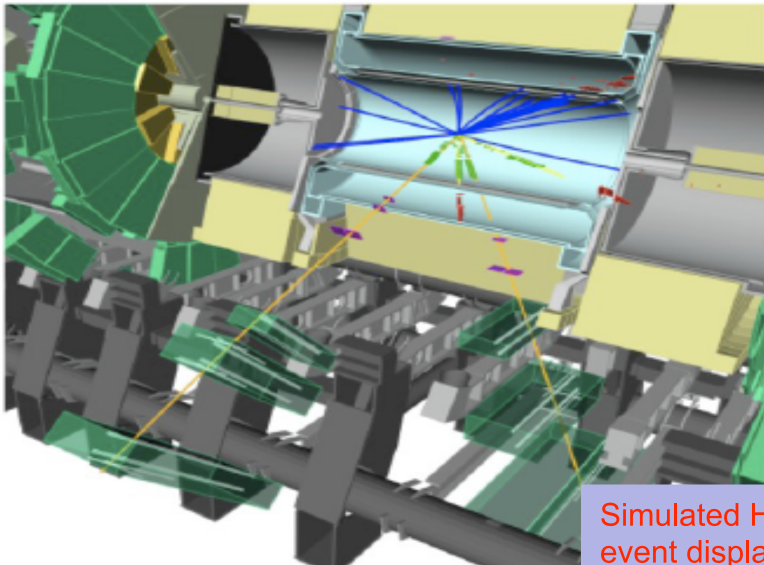


H→4e

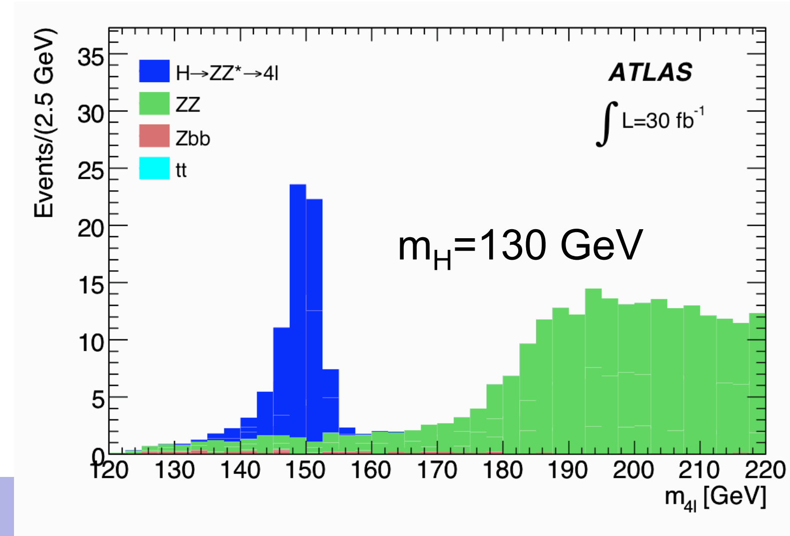


Transverse impact parameter significance in signal and reducible background events.

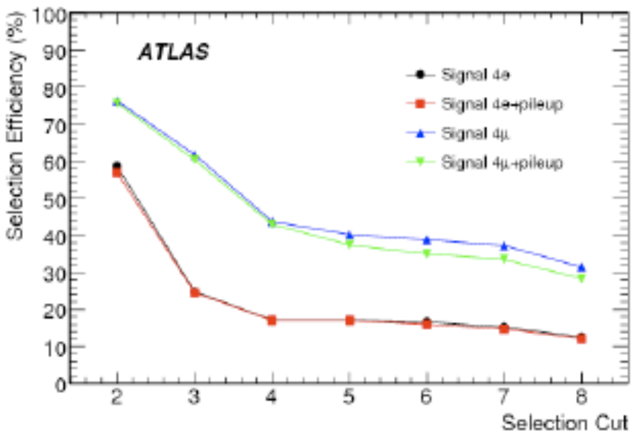
Higgs → ZZ* → 4l

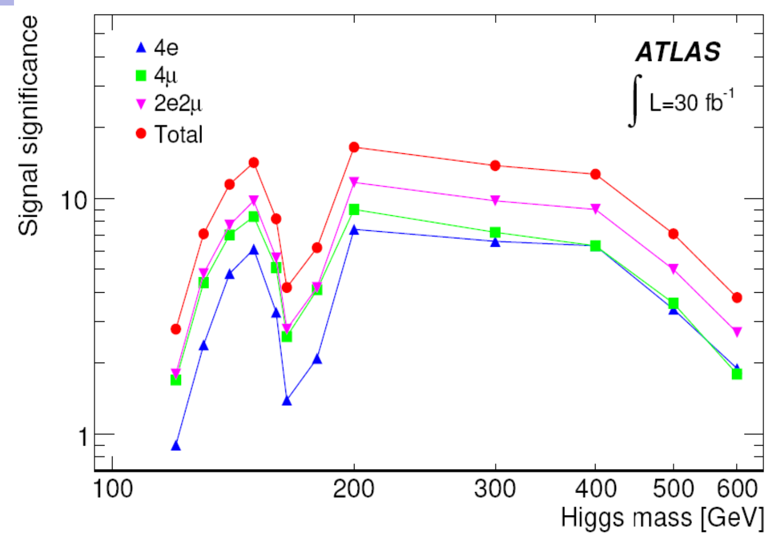


Simulated H→2e2μ event display



- Pile-up and cavern background lower the signal efficiency by ~10% (M_H= 130 GeV)





5 fb^{-1} to claim discovery ~ m_H=150 GeV or 200<m_H(GeV)<400

$H \rightarrow WW(*)$

Interesting for $2M_W < M_H < 2M_Z$ *where all other decay modes are suppressed.*

Signature is $e\mu$ *(or lqq)* $+ E_T^{miss}$.

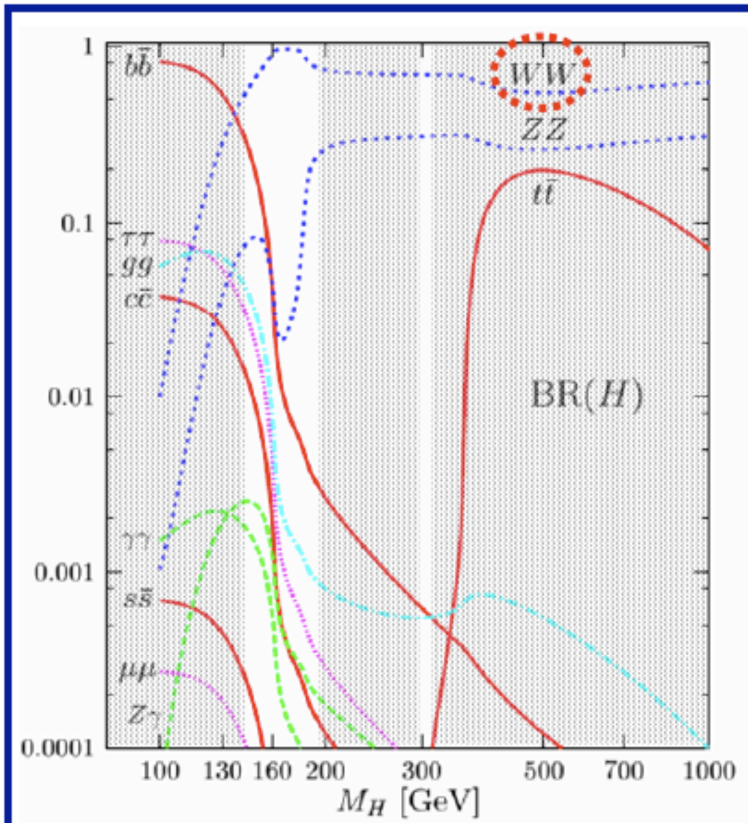
ATLAS

Three channels:

- $- H \rightarrow WW \rightarrow e\,\nu\,\mu\,\nu$ *(H+0jet)*
- $- H \rightarrow WW \rightarrow e\,\nu\,\mu\,\nu$
- $- H \rightarrow WW \rightarrow l\,\nu\,q\,q$ *(only for* M_H*=300 GeV)*

VBF (H+2jet)

Measure of spin and CP properties possible for heavy $H \rightarrow WW \rightarrow lvqq$



Comments:

- No mass peak ➔ use transverse mass. $M_T = \sqrt{(E_T^{ll} + E_T^{\nu\nu})^2 - (\vec{p}_T^{e\mu} + \vec{p}_T^{miss})^2}$
- **High backgrounds**: *WW, Wt, ttbar, Z➔2l, bb,cc,QCD multijet*

ATLAS: ee, μμ analysis in preparation

$H \rightarrow WW \rightarrow \ell\nu\ \ell\nu$

$gg \rightarrow H \rightarrow W W^*$
$\rightarrow \ell\nu\ \ell\nu$

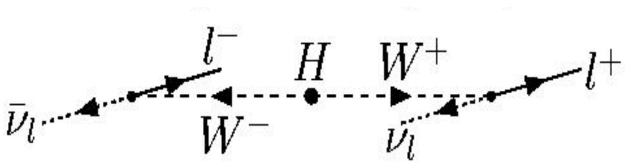
M. Dittmar and H. Dreiner
arXiv:hep-ph/9608317v1

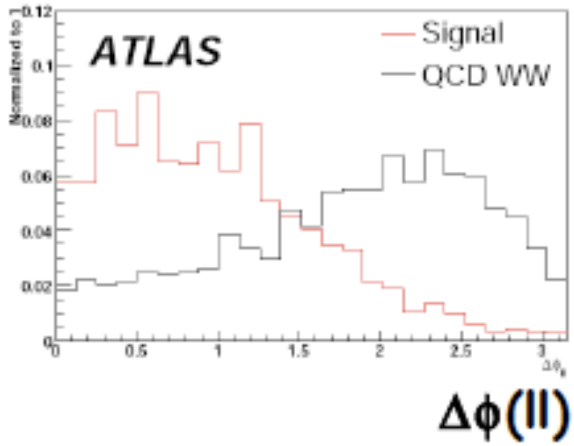
$qq\ H \rightarrow qq\ W W^*$
$\rightarrow qq\ \ell\nu\ \ell\nu$

- Large $H \rightarrow WW$ BR for m_H ~ 160 GeV/c^2
- Neutrinos → no mass peak,
- Large backgrounds: WW, Wt, tt

<u>Two main discriminants</u>:

(i) Lepton angular correlation

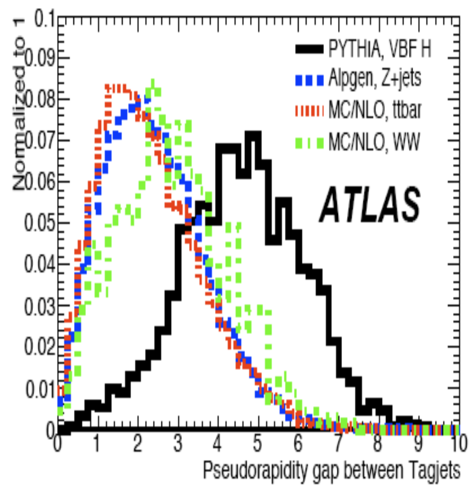


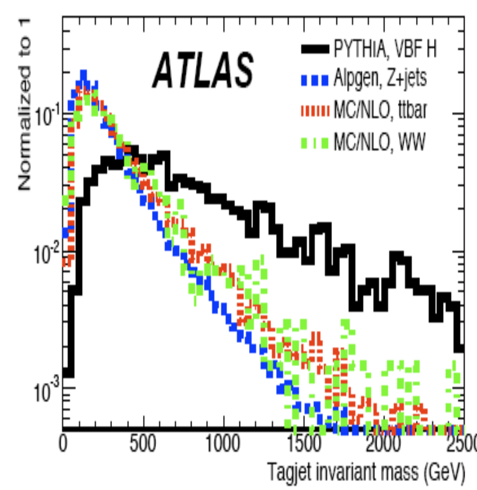


Selection criteria:
- Lepton P_T cuts and tag jet requirements ($\Delta\eta$, P_T)
- Require large mass of tag jet system
- Jet veto (important)
- Lepton angular and mass cuts

$$M_T = \sqrt{(E_T^{ll} + E_T^{\nu\nu})^2 - (\vec{p}_T^{e\mu} + \vec{p}_T^{miss})^2}$$

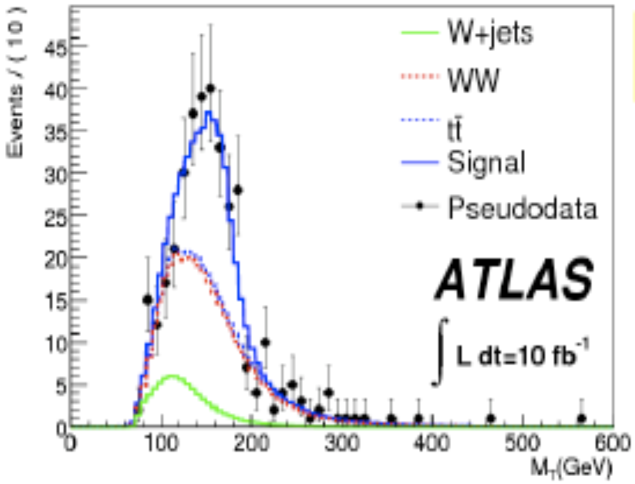
(ii) for VBF: jet veto (no jet activity) in central detector region



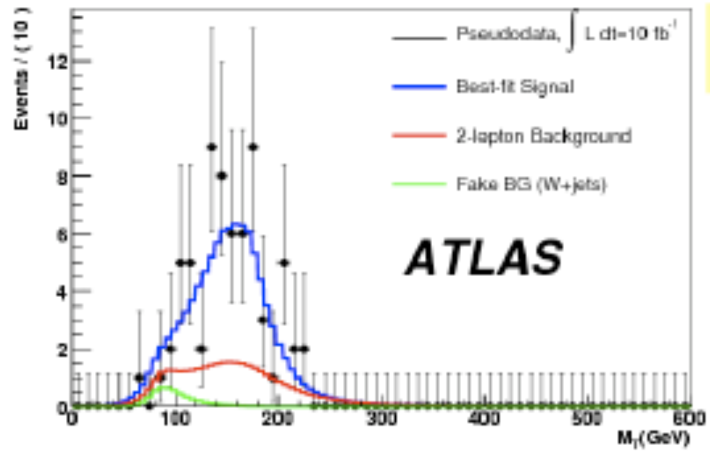


<u>Difficulties:</u>
(i) need precise knowledge of the backgrounds
Strategy: use control region(s) in data, extrapolation in signal region
(ii) jet veto efficiencies need to be understood for signal and background events
→ reliable Monte Carlo generators, data driven-background normalizations

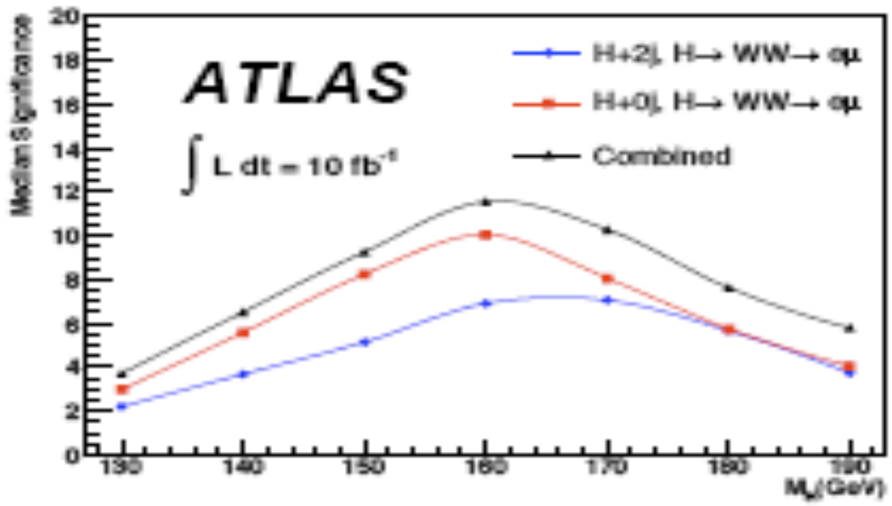
$H \rightarrow WW \rightarrow \ell\nu\,\ell\nu$



H+0jet

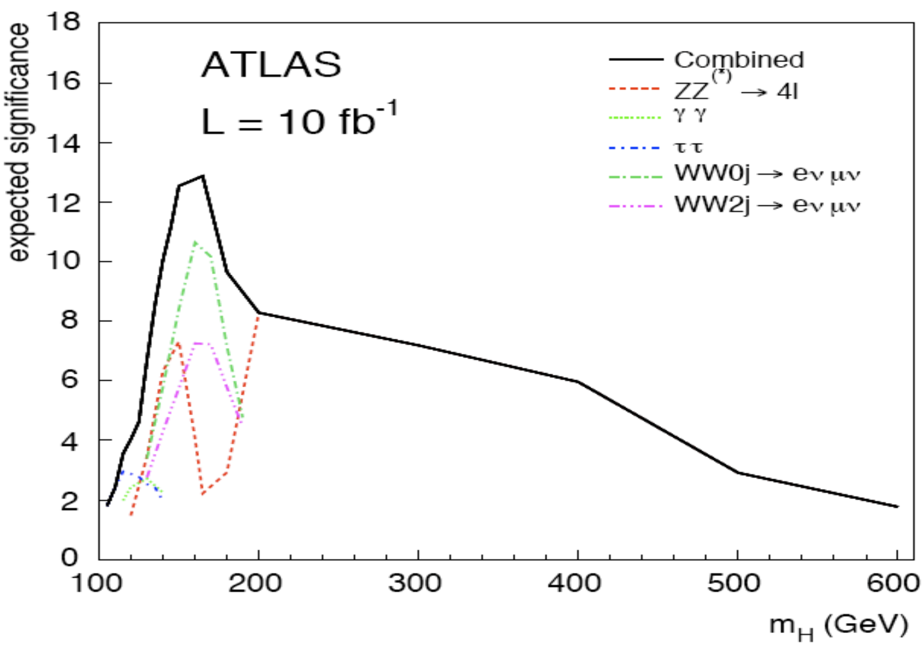


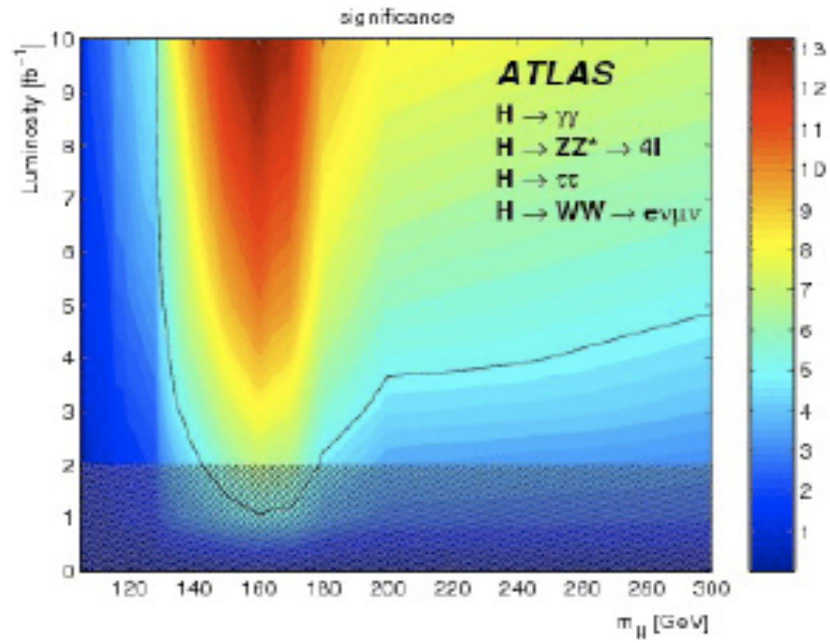
H+2jets



Significance > 5σ @ 10 fb^{-1}

ATLAS discovery potential





With 2 fb^{-1}, > 5σ discovery in 143 < m_H(GeV) < 179

- Full mass range can already be covered after a few years at low luminosity
- Several channels available over a large range of masses

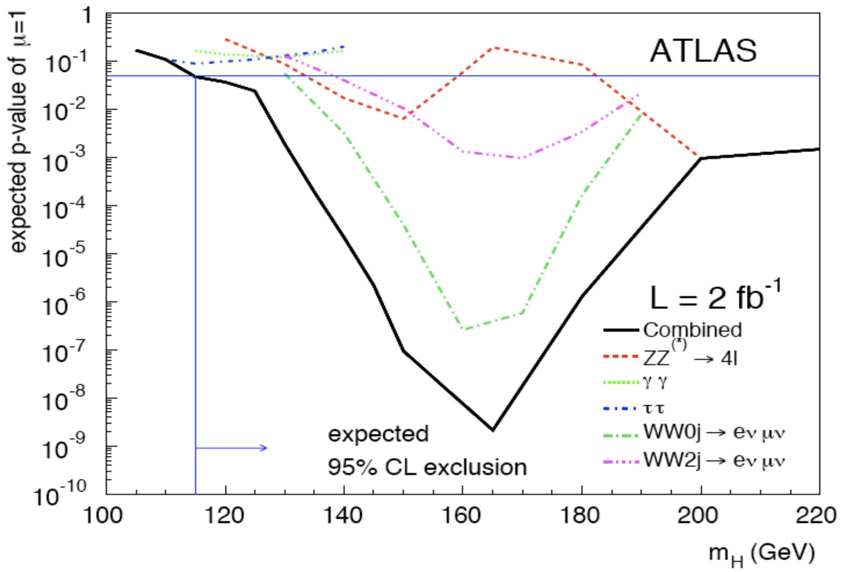
Vector boson fusion channels play an important role at low mass !

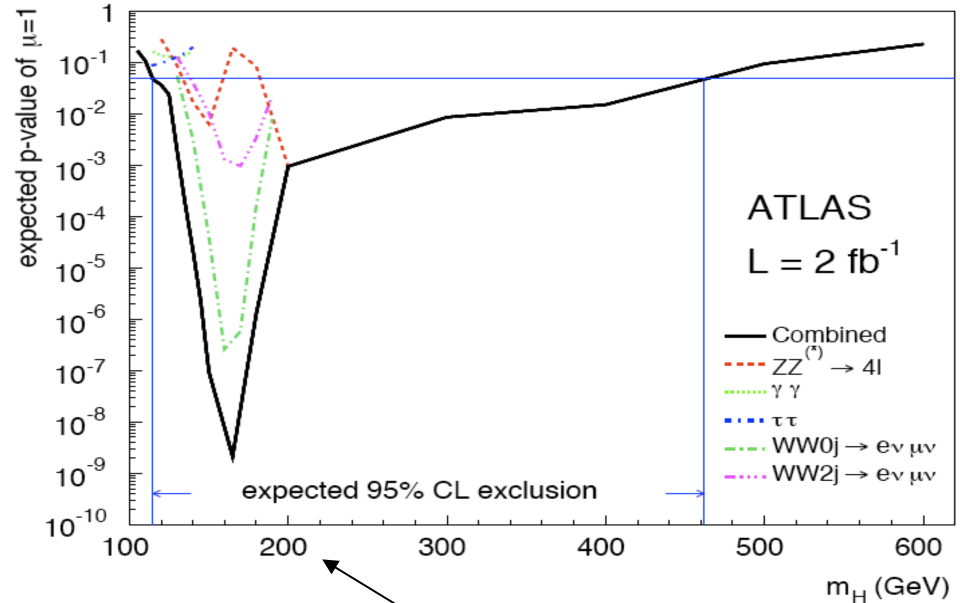
Important changes w.r.t. previous studies:

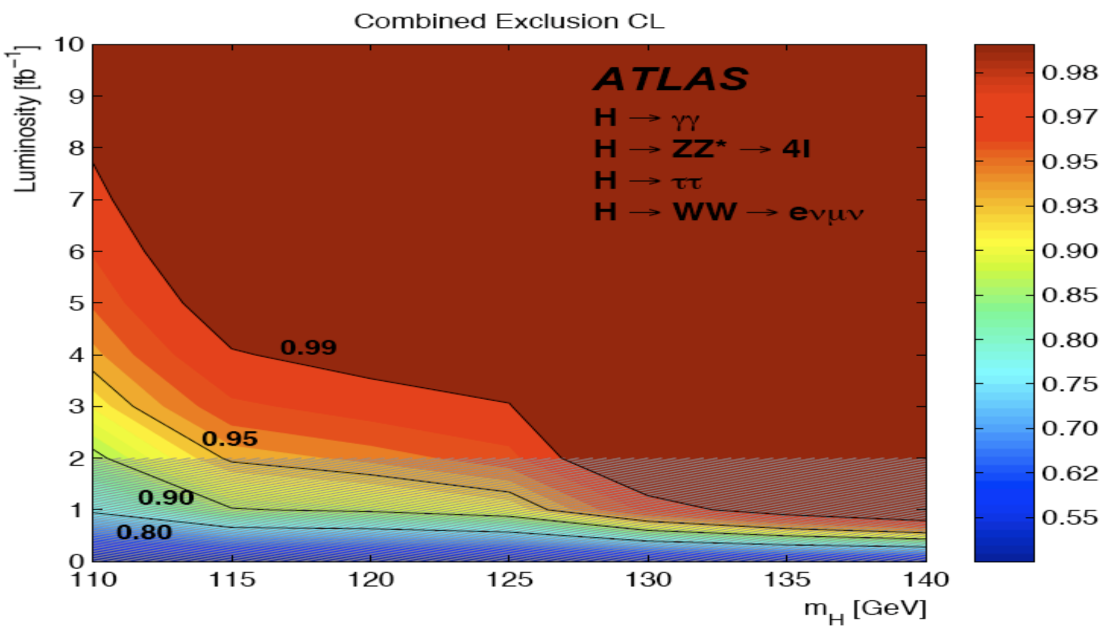
- **H → γγ** sensitivity of ATLAS and CMS comparable
- **ttH → tt bb** disappeared in both ATLAS and CMS studies:

Recover some sensitivity in the highly boosted Higgs regime – see the talk of M. Schumacher for details

ATLAS Combined Exclusion Limit





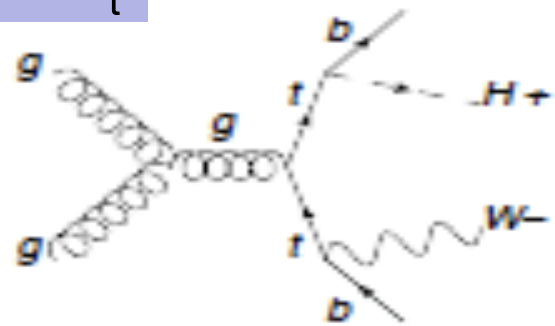


$m_H > 115$ GeV at 95% CL with 2 fb^{-1}

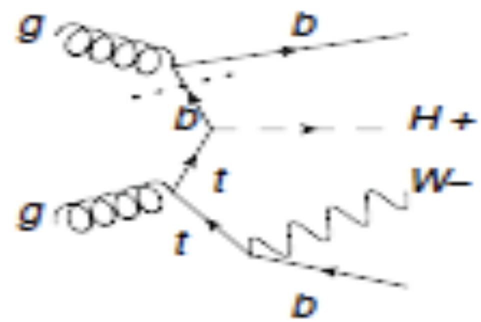
Luminosity required for exclusion as function of m_H

Charged Higgs Boson

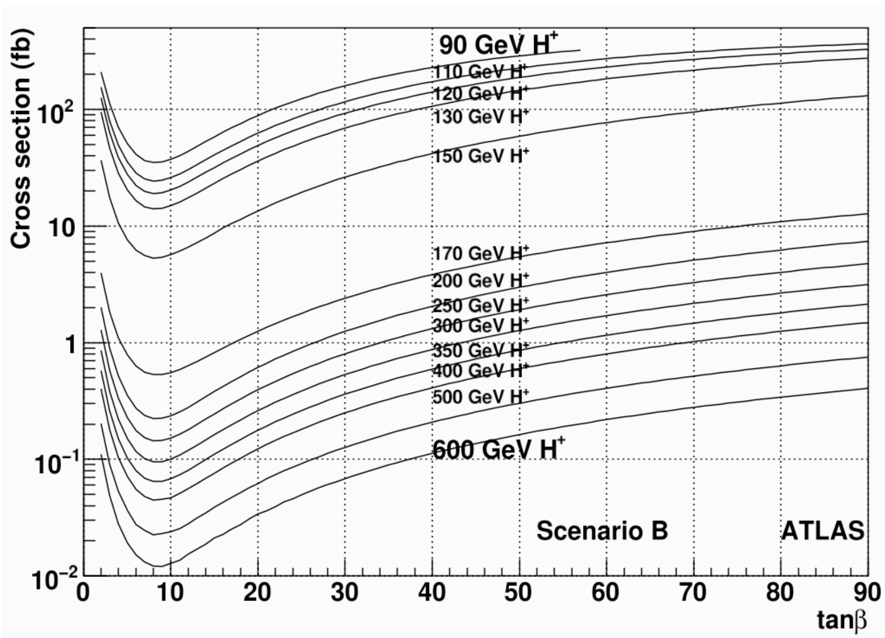
$m_{H+} < m_t$

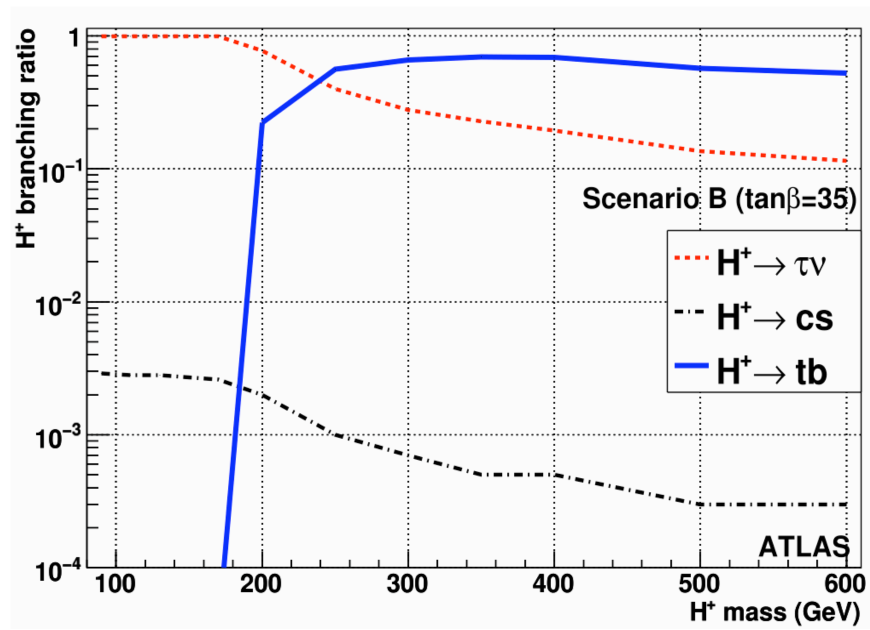


$m_{H+} > m_t$



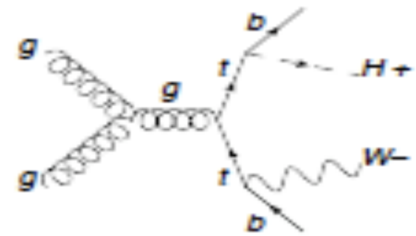
m_h max scenario

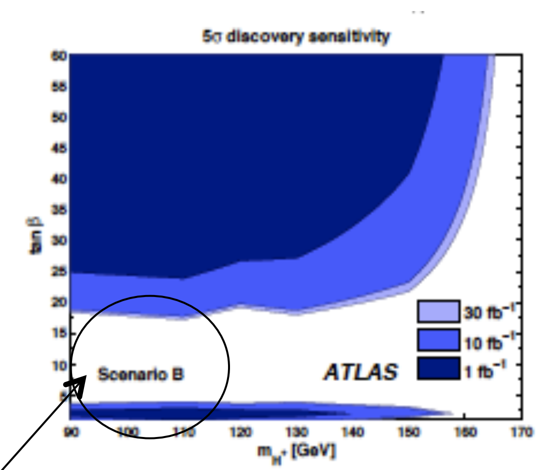




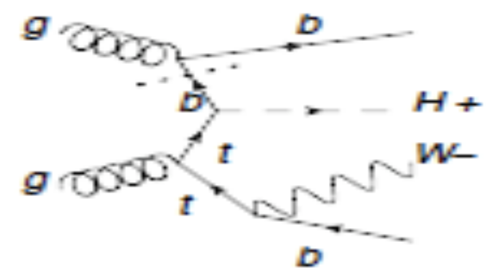
Charged Higgs Boson

- Light Charged Higgs boson: $m_{H+} < m_t$
  - $b\tau$(had)ν bW(had)
  - $b\tau$(lep)ν bW(had)
  - $b\tau$(had)ν bW(lep)
  - di-lepton analysis in progress
  - Major background is tt $\rightarrow$ bWbW
  - Reliance on b-tagging, τ-jet, lepton identification and MET performance
  - For hadrornic decay of W, reconstruction t $\rightarrow$ bjj invariant mass
  - For leptonic decay of W, use lepton-τ charge correlation
  - For hadronic τ, higher branching fraction, but τ-trigger essential if W decays hadronically
  - For leptonic τ, use lepton-top angular correlation

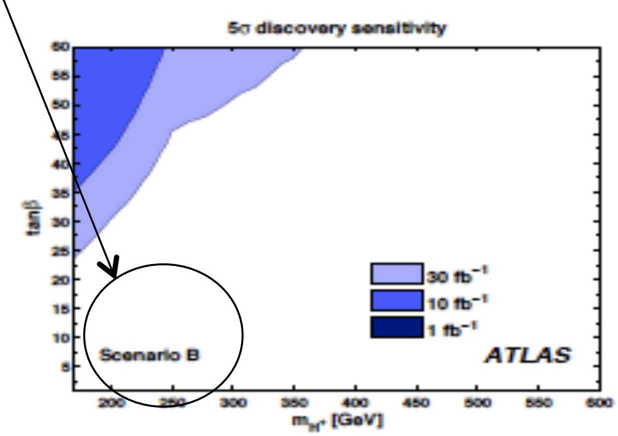




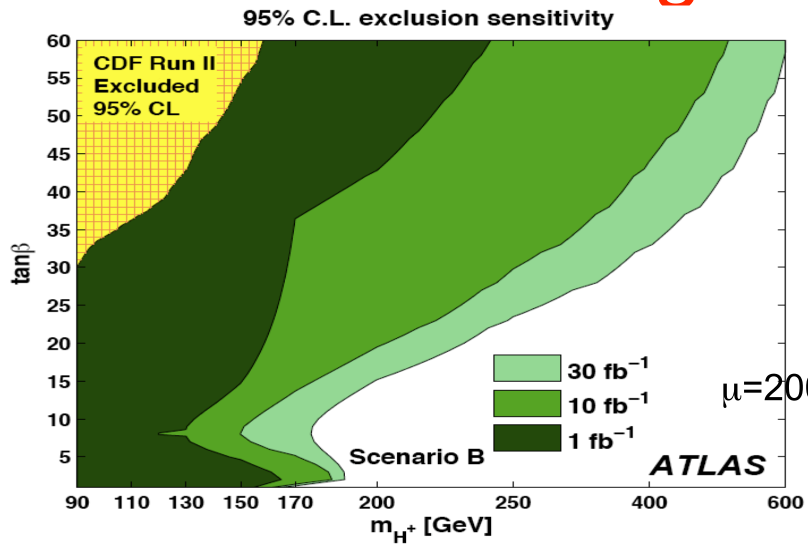
Scenario B = m_h max scenario



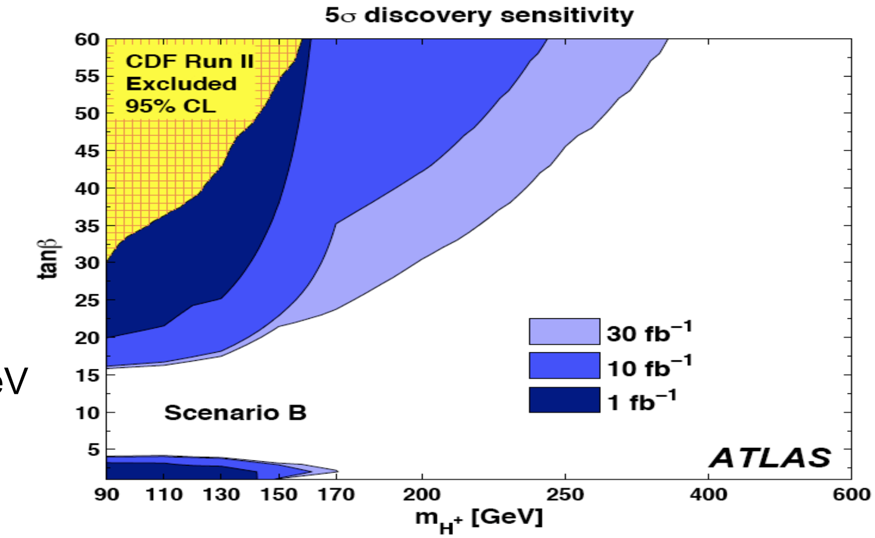
- Heavy Charged Higgs boson: $m_{H+} > m_t$, 2$\rightarrow$ 2 + 2$\rightarrow$ 3 processes
  - t $\rightarrow$ bW (lep) $H^+ \rightarrow$ tb $\rightarrow$ bb W (had)
  - t $\rightarrow$ bW (had) $H^+ \rightarrow \tau$ (had) ν ← fully hadronic channel (most sensitive)
  - Fully hadronic: reconstruction top as (bjj), reconstruction H^+ transverse mass from MET and τ-jet system
  - Backgrounds: tt, ttbb, ttjj, W+jets, single top, QCD multi-jets → Exploit the helicity correlation τ-polarization in W (spin 1) → $\tau\nu$ versus H^+(spin 0) → $\tau\nu$



Charged Higgs Boson



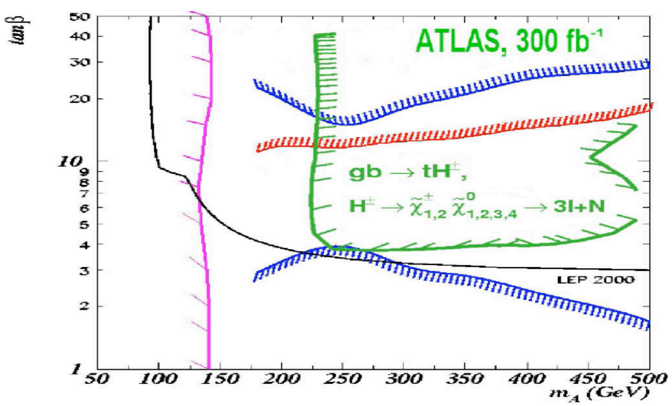
μ=200GeV

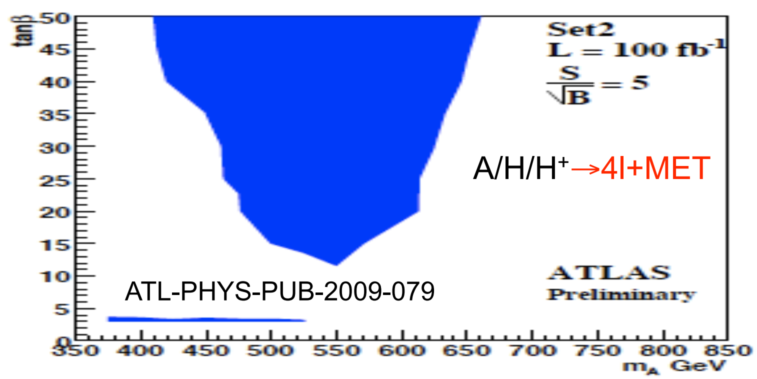


Wedge region could be covered with $H^+ \rightarrow$ SUSY

Eur. Phys. J. C 44 (2005) s11

$gg \rightarrow tbH^+$, $H^\pm \rightarrow \chi_{2,3}^0\, \chi_{1,2}^\pm \rightarrow 3\ell + E_T^{miss}$





ATL-PHYS-PUB-2009-079

- Exclusions depend on MSSM parameters (slepton masses)
- More systematic studies are needed

(initiated by A. Djouadi et al., also started in ATLAS with benchmark points proposed by S. Heinemeyer)

Higgs Cross Sections and BR as Function CM Energy

- CSC Note common reference for inclusive SM Higgs cross section (ggF, VBF, associated with W/Z and associated with tt) and branching ratio at 14 TeV
  - Calculation based on M. Spira's programs (ggF at NLO - HIGLU)
  - Updated version of HQQ with ttH at NLO
  - CTEQ6 pdf set
  - No additional EW+QCD NLO corrections included

- Update the Higgs production cross sections and decay branching ratios of SM, MSSM (Example: NNLO+NNLL for gg-fusion) using the most recent calculations and codes. Center of mass energy: 10 TeV
- Prepare the tools needed to calculate *quickly* Higgs production cross section at different CM energies

$gg \rightarrow H$, VBF Cross Sections and BR

1. Total cross section
   - ggF HIGLU (NLO) and HggTotal (NNLO) results
   - HggTotal NNLO K-factors and additional corrections

2. HO EW and QCD corrections S. Actis et al., [arXiv:0809.3667]
   - EW NLO corrections to $H \rightarrow \gamma\gamma$ and $gg \rightarrow H$: waiting for numbers by A. Vicini
   - EW two-loop corrections to $H \rightarrow \gamma\gamma$ (with HggTotal)

3. Differential distributions
   - no news on $H \rightarrow WW^{(*)} \rightarrow ll\nu\nu$ and $H \rightarrow ZZ^{(*)} \rightarrow 4l$
   - Study of VBF will probably take longer

4. PDF uncertainties
   - ggF NLO and NNLO studies done, ggF HIGLU NLO studies to come

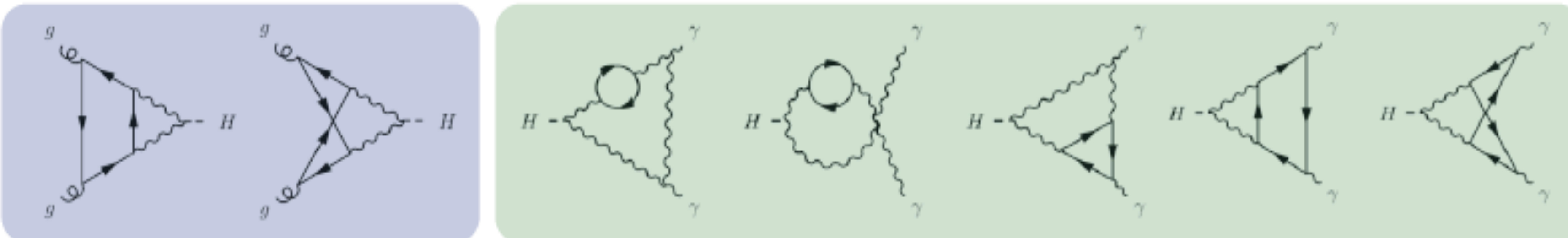
5. Higgs p_T
   - Pythia/Herwig comparison

6. Branching ratios
   - Waiting for EW NLO corrections from A. Vicini *et al.*

EW corrections to gg→H and H→γγ

[U. Aglietti, R. Bonciani, G. Degrassi, A. Vicini, F. Maltoni]

- Two loop EW correction to ggF Higgs production and to H→γγ decay



  - Light fermion contribution evaluated exactly
  - Contribution of t and b approximated with an expansion valid up to $2M_W$ (for $M_H > 2M_W$ contributions expected to be small)
  - Top contribution is at most 15% of the light fermion one and has opposite sign

- EW corrections factorize and can be treated as a K factor which redefines the lowest order partonic cross section

$$\hat{\sigma}_0 \rightarrow \hat{\sigma}_0(1 + \delta_{EW}(M_H))$$

- Corrections to the H→γγ decay used to recalculate BR

gg → H, VBF Cross Sections and BR

- **HIGLU results at NLO** for 10 TeV, including scale uncertainties (only for the NLO)
- **HggTotal NLO results,** for sake of comparison
  - cross section accuracy 0.1%
  - MSTW2008NLO pdf set
- ***Low mass range***

m_H [GeV]	σ_{LO} [pb]	σ_{NLO} [pb]	$\mu = 0.5m_H$ [%]	$\mu = 2m_H$ [%]	$\sigma^{HggTotal}_{NLO}$ [pb]
100.	15.616	29.283 ± 0.010	0.191	0.145	32.96668
105.	14.246	26.752 ± 0.009	0.191	0.145	30.08914
110.	13.0456	24.527 ± 0.008	0.191	0.146	27.60862
115.	11.988	22.572 ± 0.007	0.190	0.146	25.32288
120.	11.050	20.839 ± 0.007	0.190	0.146	23.40484
125.	10.216	19.296 ± 0.006	0.190	0.146	21.60744
130.	9.4704	17.917 ± 0.006	0.190	0.146	19.98836
135.	8.8011	16.678 ± 0.005	0.190	0.147	18.58033
140.	8.198	15.562 ± 0.005	0.190	0.147	17.27225
145.	7.654	14.553 ± 0.005	0.189	0.147	16.14309
150.	7.160	13.639 ± 0.004	0.189	0.147	15.12264
155.	6.712	12.807 ± 0.004	0.189	0.147	14.17572
160.	6.304	11.358 ± 0.004	0.189	0.096	13.32085
165.	5.931	11.358 ± 0.004	0.189	0.148	12.53190
170.	5.590	10.725 ± 0.003	0.189	0.148	11.80214
175.	5.278	10.144 ± 0.003	0.188	0.148	11.15230
180.	4.991	9.610 ± 0.003	0.188	0.148	10.55042
185.	4.727	9.118 ± 0.003	0.188	0.148	9.98747
190.	4.484	8.665 ± 0.003	0.188	0.148	9.50906
195.	4.259	8.246 ± 0.003	0.188	0.149	9.03711
200.	4.052	7.859 ± 0.002	0.188	0.149	8.58974

discrepancies HIGLU/HggTotal O(10%) - HIGLU results with MRST2008NLO under preparation

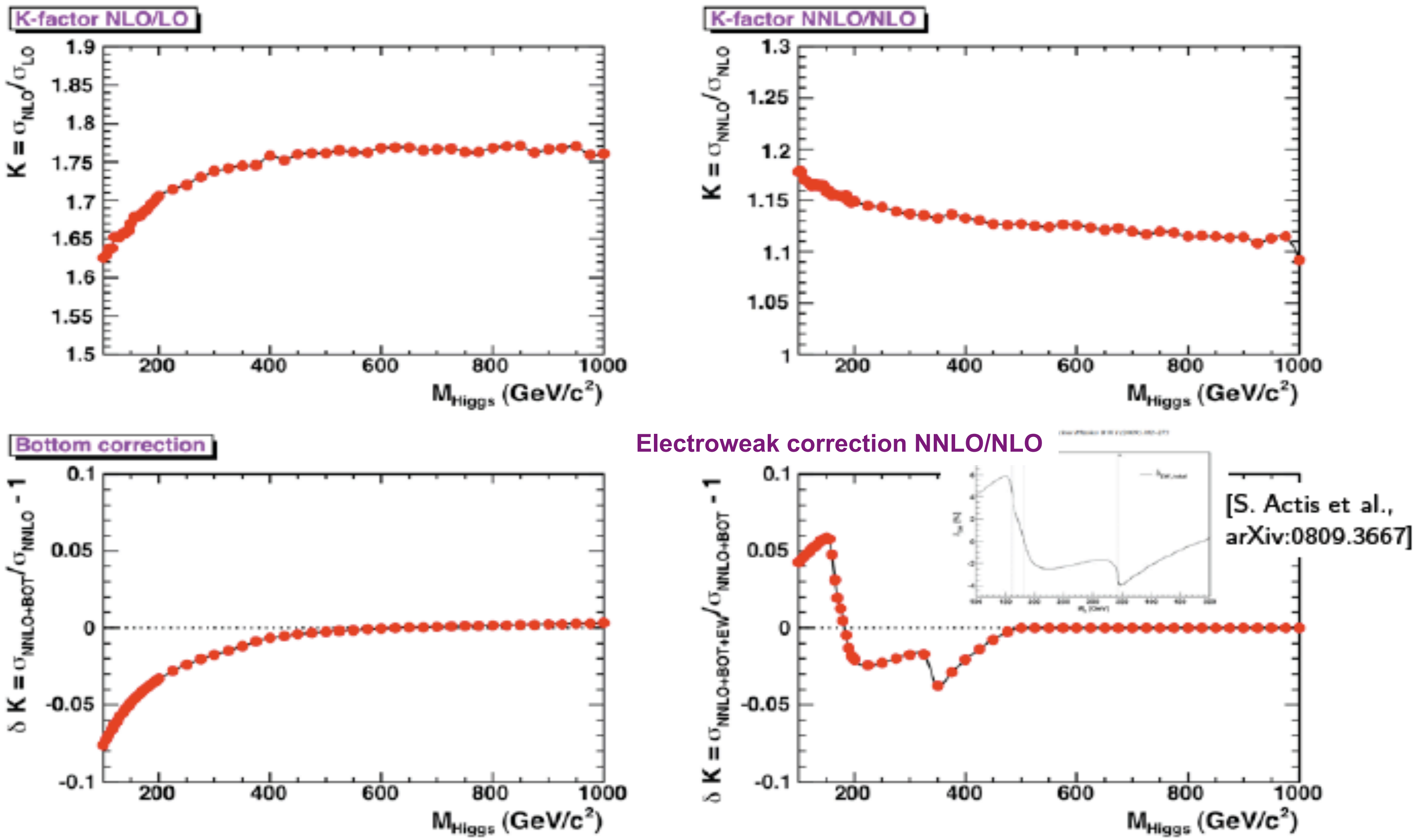
gg → H, VBF Cross Sections and BR

HggTotal recent implementations:

- NNLO EW corrections for gg→H [S. Actis et al., arXiv:0809.3667]:
  - $m_t = 172.7$ GeV (ATLAS 172.5 GeV)
  - Light fermion 2-loop EW extended to complex mass scheme
- Mixed EW-QCD corrections C. Anastasiou et al., arXiv:0811.3458
- Bottom quark mass:
  - Pole mass (4.75 GeV) or MS-bar running mass (3.609 GeV@10 GeV)? 2% difference in total cross section at $m_H = 200$ GeV
  - Running mass is preferred for LO, but difference is small at NLO
- More to come:
  - EW corrections to Higgs+1-jet by F. Petriello *et al.*
  - Finite mass quark effects at NLO - **Hpro** [C. Anastasiou et al. arXiv:0907.2362]
  - HggTotal goes into FEHiP

gg → H, VBF Cross Sections and BR

- gg→H - **HggTotal+MSTW2008** $\sqrt{s}$=10 TeV, $\mu_R = \mu F = m_H/2$



Charged Higgs → SUSY

Based on the 4 benchmark points of S. Heinemeyer

- Cross Section ($gb \to tH+$):
  - A1: 0.0087 pb
  - A2: 0.014 pb
  - B1: 0.0085 pb
  - B2: 0.013 pb
- BR($H+ \to \chi_i^+ \chi_j^0$):
  - A1: 0.73
  - A2: 0.56
  - B1: 0.35
  - B2: 0.19

Designed for $H^+ \to \chi_i^+ \chi_j^0 \to$ 3 leptons + X study

M_A=390 GeV	M_SUSY=1000 GeV
A_t=A_b=2000 GeV	M_3=800 GeV
M_stau (L,R)=250 GeV	M_slepton (L,R)=150 GeV
A_tau=A_l=0	

Scenario A: mu=135 GeV, M_2=210 GeV; tan β=7 and 15

Scenario B: mu=200 GeV, M_2=310 GeV; tan β=7 and 15

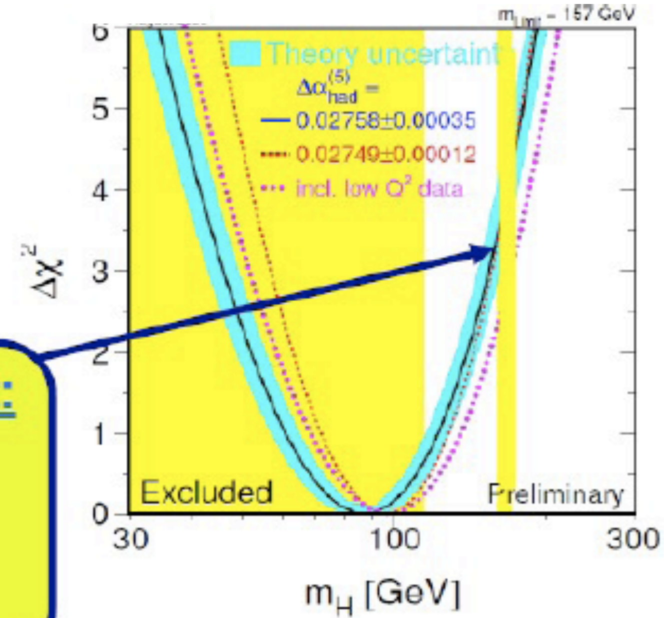
Summary

- **Exclusion**
  - With 2 fb^{-1} (one experiment), exclude at 95% CL the existence of SM-like Higgs with m_H>115 GeV, if it does not exist
- **Higgs Searches**
  - ATLAS is well-prepared to discover Higgs bosons. The SM mass range and the MSSM parameter space are well covered
  - With 1-2 fb^{-1}, discovery possible in $H \to WW \to ll\nu\nu$ depending on m_H. > 5σ discovery possible in 143 < m_H(GeV) < 179
  - With 10 fb^{-1}, normally 1 year of low luminosity operation, discovery possible for $m_H \in$ [120, 500] GeV
- **For now, the focus is on early data analysis preparation**
  - Focus on the understanding of the detector performance
  - Early physics – J/Psi → $\mu\mu$, minimum bias, etc
  - Developing data driven background estimation methods
  - Focus on the SM background measurements to Higgs boson searches
  - With theorists, preparing tools to compute Higgs boson cross-sections and branch ratio as function of CM energy
  - Preparing statistical tools for combined exclusion limits

BACKUP

Higgs Searches: present limits

- Latest results from Tevatron presented at Lepton-Photon '09 conference (August 2009)

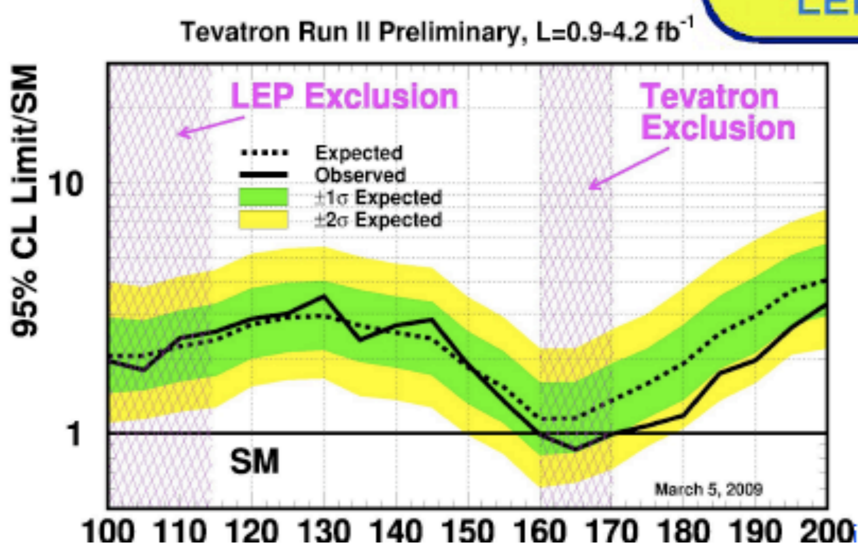


Precision EW fit:

m_H < 157 GeV

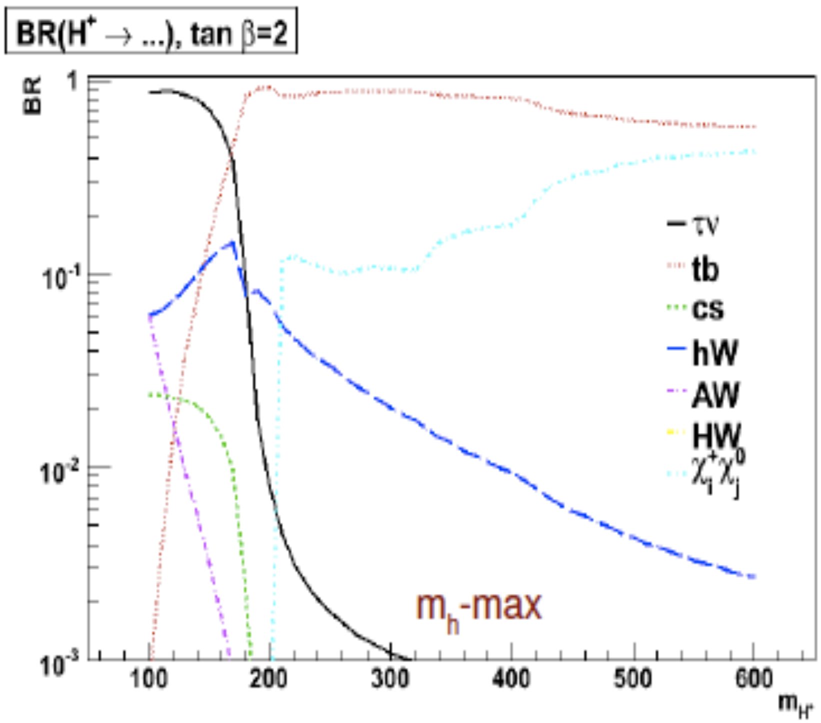
@95%CL

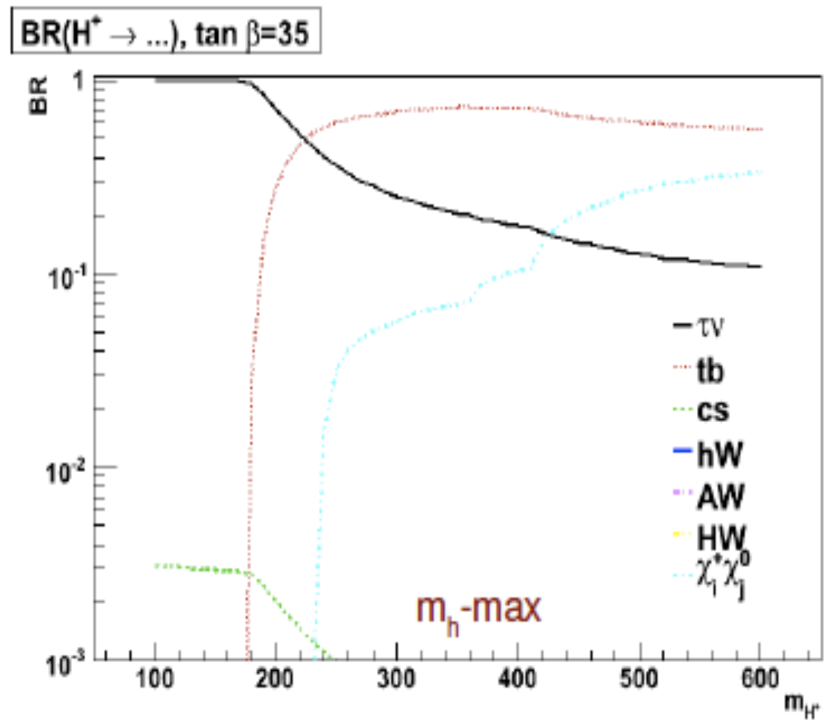
(<186 GeV with LEPII Limit)



- Updated results available for CDF and D0, but no new combined results yet....

Charged Higgs

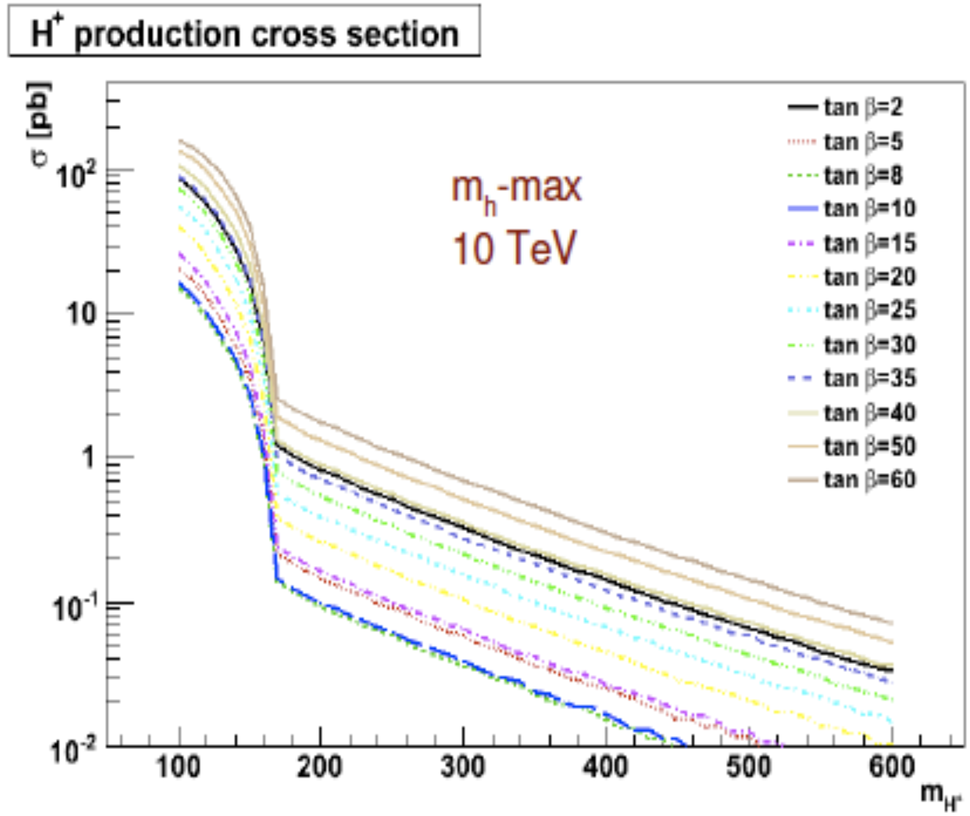




- BR(H+→...): FeynHiggs 2.6.5
- tan β: 2...70
- m_{H+}: 100...600 GeV

Charged Higgs

- $\sigma(pp \to tt \to bH{+}bW)$
  for $m_{H+} \ll$ mtop
  $=2*\sigma(tt)*BR(t \to bH+)*(1-BR(t \to bH+))$
- $\sigma(gb \to tH+)$ [w/o intermediate tt]
  for $m_{H+} \gg$ mtop
- sum of both
  for $m_{H+} \approx$ mtop

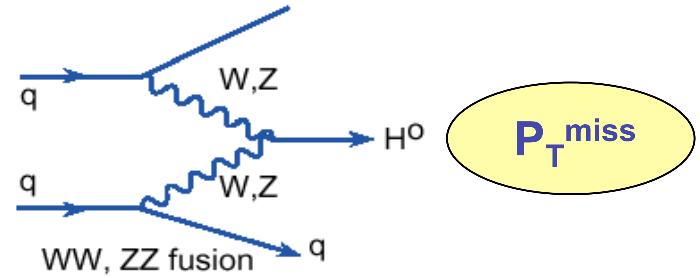


- Ingredients:
  - $\sigma(tt)$: top group (401.6 pb)
  - $BR(t \to bH+)$: FeynHiggs 2.6.5
  - $\sigma(gb \to tH+)$: Code from Tilman Plehn, CTEQ6.6M

Invisible Higgs decays ?

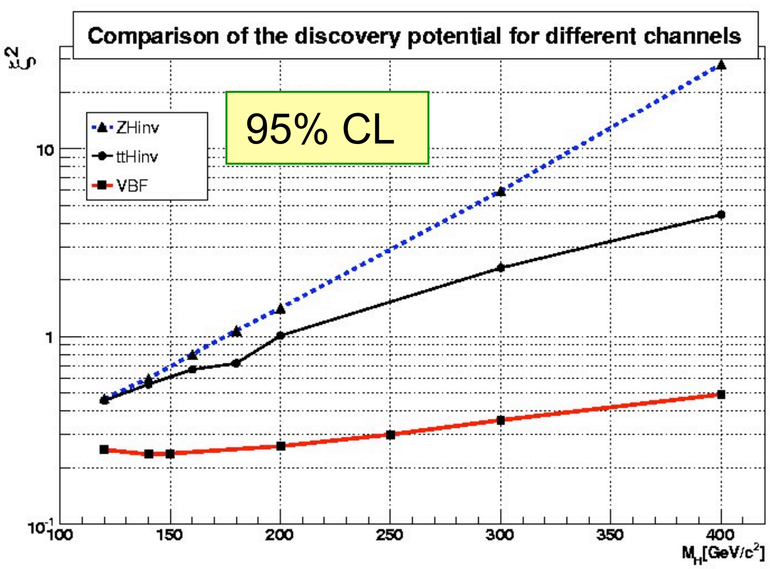
Possible searches: tt H $\rightarrow$ ℓνb qqb + P_T^{miss}
Z H $\rightarrow$ ℓℓ + P_T^{miss}
qq H $\rightarrow$ qq + P_T^{miss}

- J.F. Gunion, Phys. Rev. Lett. 72 (1994)
- D. Choudhury and D.P. Roy, Phys. Lett. B322 (1994)
- O. Eboli and D. Zeppenfeld, Phys. Lett. B495 (2000)



All three channels have been studied:
key signature: excess of events above SM backgrounds with large P_T^{miss} (> 100 GeV/c)

Sensitivity: $$\xi^2 = Br(H \rightarrow Inv.)\frac{\sigma_{qq \rightarrow qqH}}{\sigma_{qq \rightarrow qqH}|_{SM}}$$



ATLAS preliminary

Problems / ongoing work:

- ttH and ZH channels have low rates
- More difficult trigger situation for qqH
- backgrounds need to be precisely known (partially normalization using ref. channels possible)
- non SM scenarios are being studied at present first example: SUSY scenario

Invisible Higgs decays ?

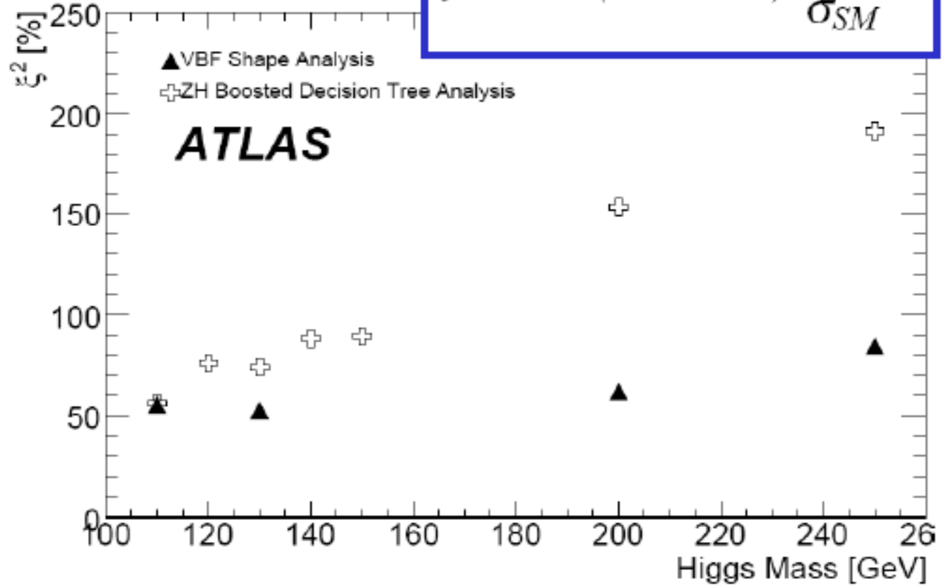
Higgs→Lightest Susy Particle

Two production modes analyzed:

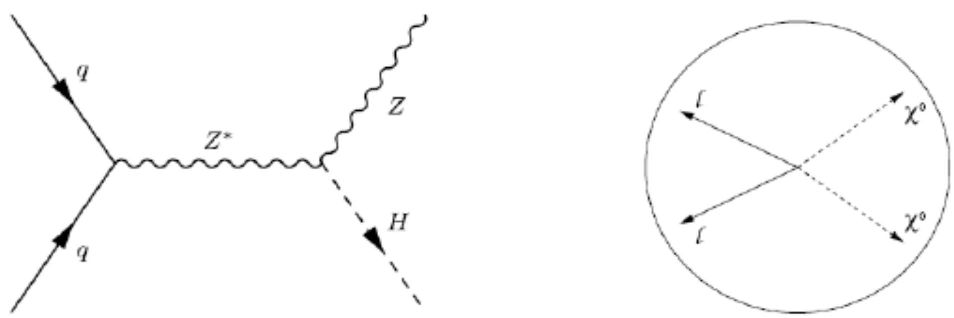
- **Associated production** *ZH*.
  - Background from $ZZ \to ll\nu\nu$.
  - Too much background to analyze *WH*.
- **VBF**.
  - Backgrounds from *QCD-dijets*, *W+jets* and *Z+jets*, when leptons are outside the detector acceptance or $Z \to \nu\nu$.

Caution: there could be nonSM backgrounds…
Missing energy is crucial

$$\xi^2 = BR(H \to inv.)\frac{\sigma_{BSM}}{\sigma_{SM}}$$



Associated production:
$H \to \chi^0\chi^0$ **recoiling against** $Z \to ll$



VBF

- **State-of-the-art:** complete NLO QCD and NLO EW corrections, both O(5-10%) for integrated quantities (for distributions they are a bit larger)

  PRD 77:013002,2008 [arXiv:0710.4749] and PRL 99:161803,2007 [arXiv:0707.0381]

- The used code is a multi-channel MonteCarlo generator by S. Dittmaier *et al.*
- **Plans:**
  - compute the total cross sections, both including and excluding the *s*-channel diagrams → HERWIG does not contain them, but Sherpa does
    - when excluding the *s*-channel graphs, incoming photon contributions should be excluded too (effect at 0.5% for small Higgs)
  - scale uncertainties estimation → varying simultaneously and separately μ_R and μ_F and taking the largest variation
    - the relative size of the EW corrections is the same between MRST2004 and CTEQ6M → CTEQ6M and their error-sets used to estimate the pdf uncertainty
- differential distributions: filling these adequately with the code takes a lot of CPU time

PDF Uncertainty

Overall settings	
$\sqrt{s} = 10$ TeV	
m_H = [100,200] GeV with 5 GeV step	
m_H = [200,1000] GeV with 25 GeV step	
$\mu_R = \mu_F = m_H$	
m_t = 172.5 GeV, m_b = 4.75 GeV (pole mass)	
MSTW2008LO	$\alpha_s(m_Z)$=0.13939
MSTW2008NLO	$\alpha_s(m_Z)$=0.12018
MSTW2008NNLO	$\alpha_s(m_Z)$=0.11707

- **Plans and ongoing studies**:
  - compare the pdf uncertainties on NLO ggF cross section
    - calculated with HggTotal (Anne-Claire, Rei) $\rightarrow$ they amount to $\pm$2-3% for $m_H <$ 200 GeV and to $\pm$10% for m_H = 1 TeV - but HggTotal is undergoing some changes O($\pm$2-3%), *we probably need to update results*
    - calculated with HIGLU (Daniela) $\rightarrow$ ongoing
  - Comparison between MSTW2008 and CT09(NLO)

Branching Ratios

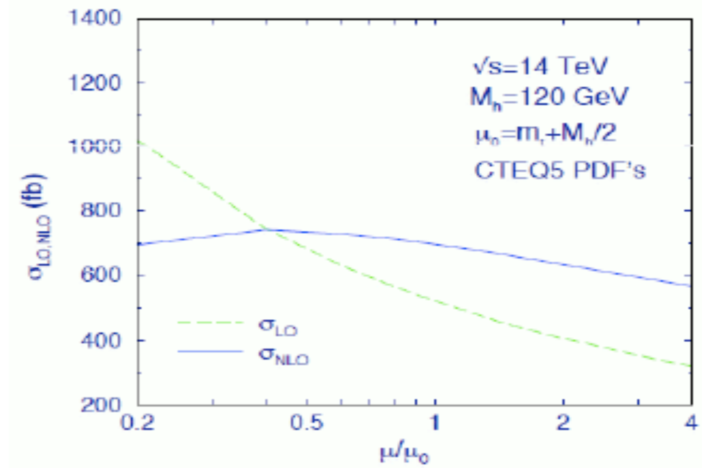
- **Branching Ratio recipe**:

$$\Gamma_H = \Gamma^{HD} - \Gamma^{HD}_{ZZ} - \Gamma^{HD}_{WW} + \Gamma^{PR}_{4f} + \Gamma^{HD}_{\gamma\gamma} \cdot (\delta^{EW}_{\gamma\gamma} + \delta^{QED}_{\gamma e+e-})$$

- **Status:**
  - HDECAY *(HD)* partial widths *calculated* using the input parameters we agreed upon, plus the following additional two: $\Gamma_W = 2.080$ GeV, $\Gamma_Z = 2.490$ GeV
  - Full set of 2-loop electroweak *(EW)* corrections to Higgs production to H→γγ decay→ *in contact with A. Vicini, numbers available soon*
  - *(PR)* = Prophecy4f results: LO and NLO corrections for all partial widths H→4 fermions, from which construct the respective results for H→$WW^{(*)}/ZZ^{(*)}$ → *numbers ready*
- **Plans:**
  - BR Calculations will be ready by our next meeting

ttH – Les Houches 2009

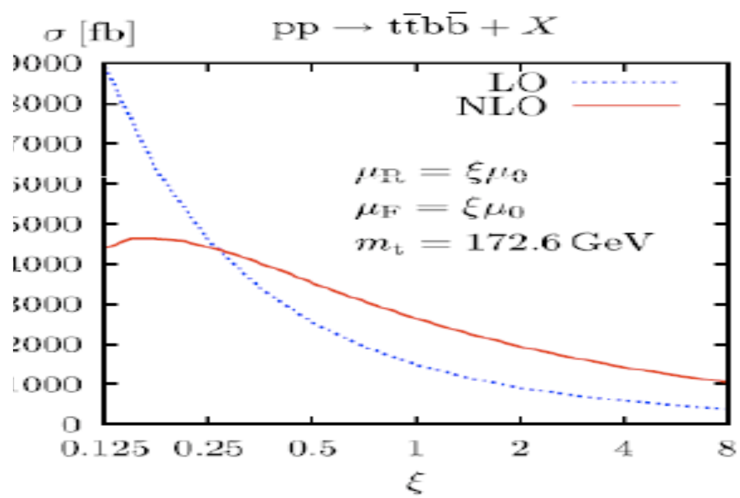
- Two independent NLO calculations have been available for a few years (Dawson et al and Beenakker et al), full agreement
- QCD k-factor 1.26
- Codes not public, interaction with authors mandatory



Dawson, Jackson, Orr, L.R., Wackeroth

- tt+1j studied in arXiv:0807.1223 (Dittmaier, Uwer, Weinzierl)
  - K-factor found to be strongly phase-space dependent

- ttbb calculated more recently in Phys. Rev. Lett. 103, 012002 (2009) (Bredenstein, Denner, Dittmaier, Pozzorini)
  - K-factor of ~1.8
  - Extra jet veto found to bring this down to ~1.2
  - Lots of interest at Les Houches
    - Impact on signal and background of such a veto, with full experimental treatment?



ttH – Les Houches 2009

- L. Reina and S. Dawson interested in organizing NLO runs from most relevant studies
  - Working group started since Les Houches 2009
  - See summary from J. Huston

So, let me ask about timescales/possibilities:

1) Adding decays to tTH
   -any more complications with having top decays compared to H?
2) pdf re-weighting

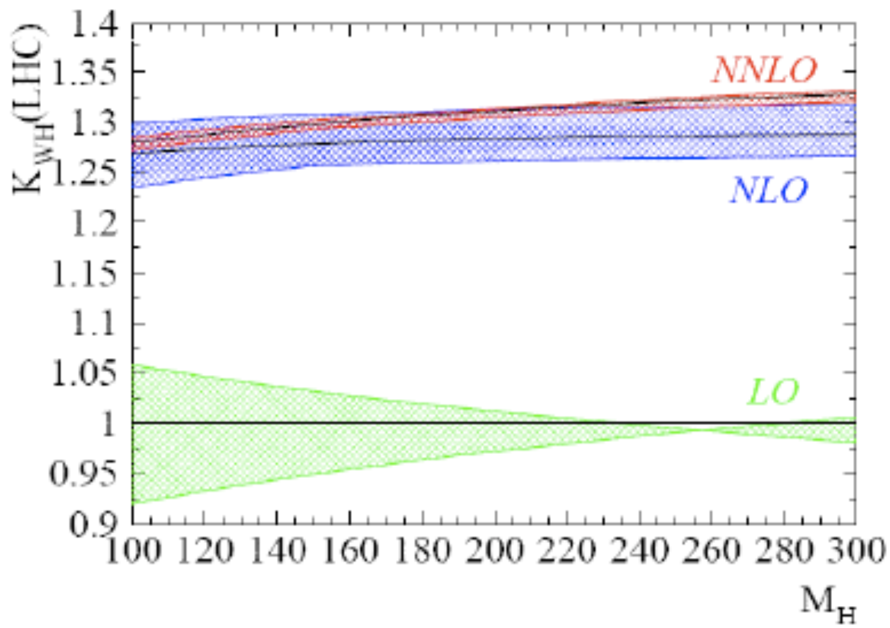
we would like to know the pdf uncertainties, if possible; the standard approach is to calculate the cross sections with a central pdf, and then to calculate the pdf weights for the error pdf's to re-weight the distributions

   -this is most often done with ROOT ntuples, but need not wait for the implementation of FROOT (although that would be nice)

3) We would like to look at differential distributions (pt, rapidity,...) for the t,T,H (and extra jet) as well as the decay products
   -in particular, we are interested in the pT distribution of the Higgs, since a boosted Higgs will improve the mass resolution, reduce the combinatorics
4) We would like to look at the resultant cross sections (acceptances) after applying the experimental cuts
   -and especially looking at the effective K-factor as a function of the extra jet pT cut
5) We would like to calculate these cross sections for several different center-of-mass energies, for several scale choices
6) We would like to apply the same considerations for the tTbB background

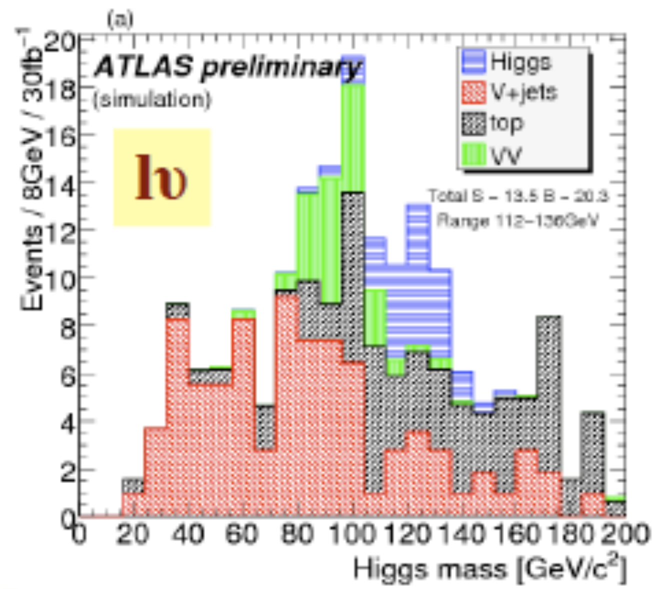
VH

- Cross-sections already known to NLO in QCD and EW (CSC book)
  - NLO QCD k-factor ~1.25
  - NLO EW k-factor ~0.9-0.95
- NNLO QCD studies in hep-ph/0307206 (Brein, Djouadi, Harlander)
  - Private code, HCSG in touch with authors
  - Push NNLO QCD + NLO EW calculation



Backgrounds to VH

- Wbb biggest problem
  - control samples clearly defined for single top and ttbar backgrounds
- Discussions pushed forward so far within Atlas by G. Piacquadio and J. Butterworth
- Accurate description of m(bb) and p_T(bb) very important for VH analysis
- Accurate rate prediction will improve sensitivity study
- Large enhancement at NLO from $qg \rightarrow Wqbb$
  - K-factor ~3
  - Additional quark in final state means jet veto reduces K-factor to <1.5
  - Theorists and experimentalists working together to understand impact of jet veto using experimental cuts in NLO calculation
  - Laura Reina is coordinating some more NLO runs, no results yet...



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