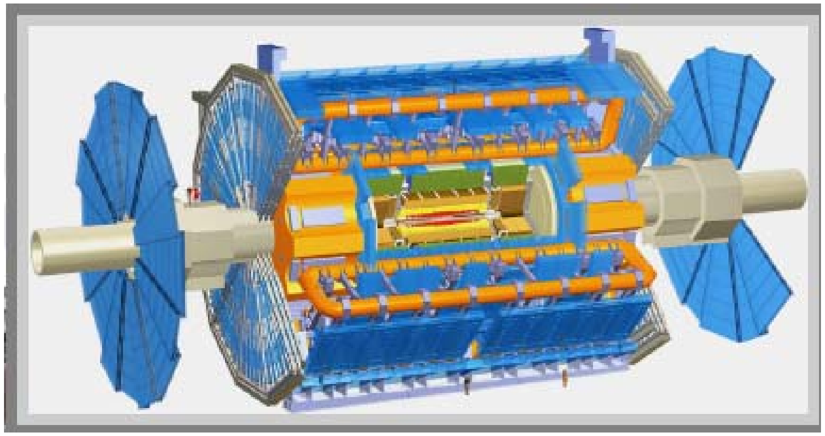
Higgs searches in ATLAS at low luminosity phase ($\mathscr{L}$ up to 30 fb^{-1})



International Linear Collider Workshop
LCWS 2007, ILC 2007
DESY, Hamburg 30 May-3 June 2007

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On behalf of the
ATLAS collaboration

DAPNIA

Outline

- Introduction
- SM Higgs searches
  - Studies of the Higgs properties
- Highlights of MSSM searches
  - CP- conserving only shown here
- Summary Conclusions
  - What to do with the first data (highlights only)

Introduction

Exploring LHC data we should answer to the following basic questions:

- Mechanism for EW symmetry breaking?
  - Through a SM Higgs boson?
  - Is there anything else (new physics , new particles) ?
- Concentrating on the search for the Higgs boson(s) we know up to now that:
  - A low mass candidate is favored
    - SM
      - From direct searches (LEP: $m_H > 114.4$ GeV)
      - From electroweak fits $m_H < 182$ GeV (@95% C.L)
    - SUSY models
      - A "light" Higgs boson is favored

LHC searches for the Higgs boson are focused in the low mass region mainly between 115-200 GeV

- variety of search channels with final states depending on the production and decay mode of Higgs boson
  - Main emphasis in semileptonic/leptonic channels
    - Pure hadronic channels too difficult to trigger on and to distinguish from the background.

Initial running conditions

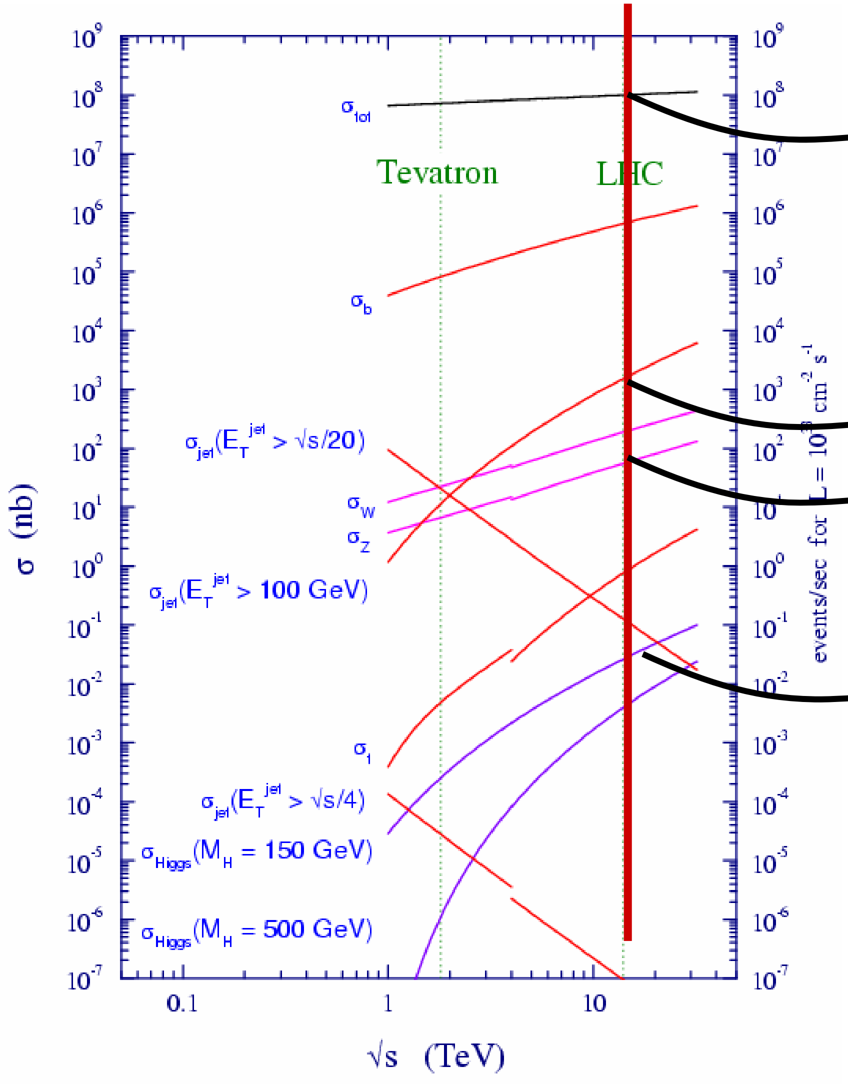
Status of the LHC Project, Ph. Lebrun, CERN
Hadron Collider Physics Symposium 2007
La Biodola, Elba, 20-26 May 2007

- First pp collisions at $\sqrt{s}$=14TeV from summer 2008

- Luminosity scenarios :
  - For 2008: $\mathcal{L} < 10^{-33}$ cm^{-2} s^{-1}, Integrated $\mathcal{L}$ up to 1 fb^{-1}
  - For 2009: $\mathcal{L} =$ 1-2 10^{-33} cm^{-2} s^{-1}, Integrated $\mathcal{L} < 10$ fb^{-1}

- In this talk main focus on:
  - Low Luminosity phase $\mathcal{L} \sim 10^{-33}$ cm^{-2} s^{-1}
    - and in particular what we can do with the first ~fb^{-1} in the Higgs searches.

Cross section and Events rate (√s=14 TeV)



Total inelastic σ ~ 80mb

Inclusive jet Production Et>100 GeV σ ~ few μb

Inclusive Z (W) σ ~ 40(140) nb

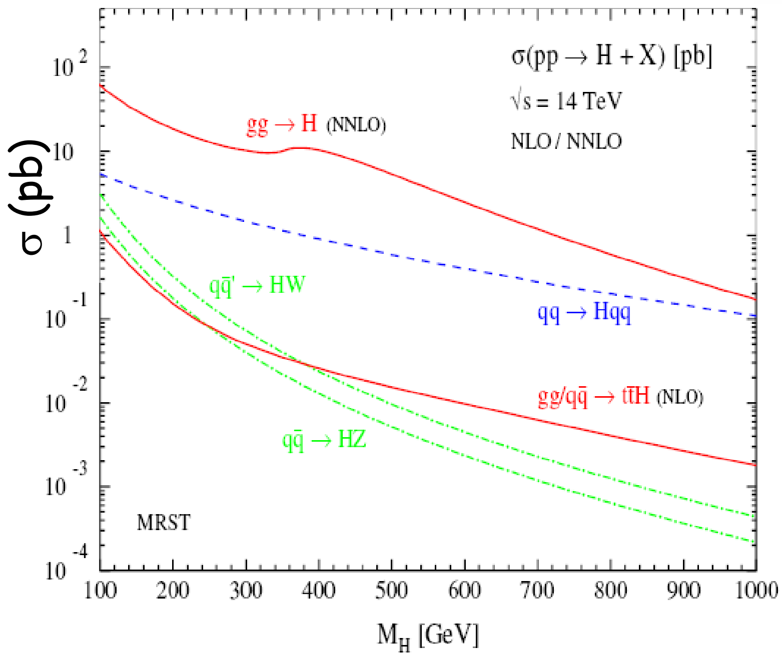
Higgs m_H 150 GeV σ ~ 30 pb

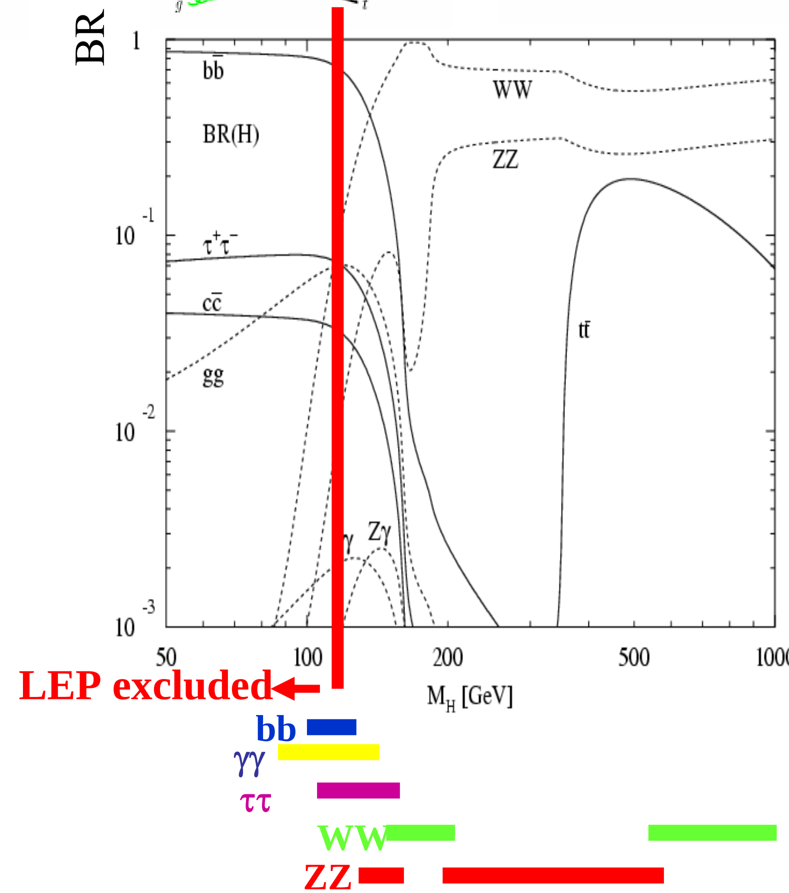
The H signal production cross section is several orders of magnitude below the main processes

Higgs production and decays of SM Higgs at LHC

Higgs main production mechanisms in order of importance

gg→H via top quark loop | Vector Boson Fusion | Associated production with top | WH, ZH production





Typical uncertainties on the cross sections

gg fusion:	~10-20 %	NNLO
VBF	: ~ 5%	NLO
ttH	: ~10 %	NLO
WH,ZH	: ~ 5%	NNLO

NLO computations for all the relevant BR
Accuracy ~ few %

Strategy to detect a SM Higgs at LHC

Key points to define the strategy for detecting the Higgs

- Production mode, branching ratios
- Background level per process

1. gg fusion dominant production

- H →$\gamma\gamma$,
- H→ZZ(*)→4l, WW(*)→2l2ν possible (for mH>130 GeV)
    - H→bb suffers from QCD background
    - H→$\tau\tau$ also difficult

2. VBF production

- H→$\tau\tau$ possible due to the distinct signature of the 2 forward jets in this mode
- H→WW channel

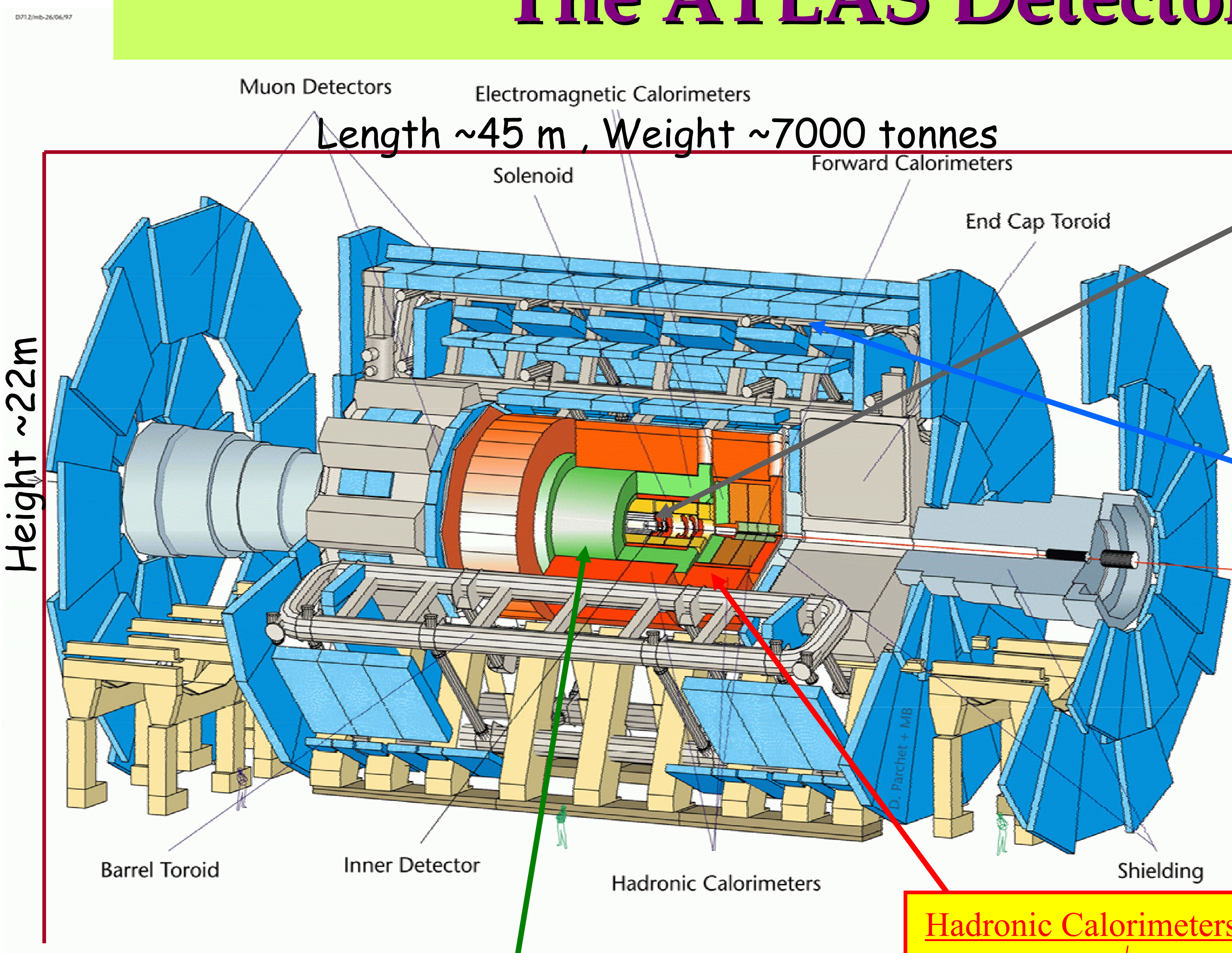
3. ttH production

- t→lepton decays for trigger, H→bb possible at low mass

4.WH,ZH production:

- *H*→$\gamma\gamma$, WW(*) decays only at high luminosity

The ATLAS Detector



Inner Detector: (Silicon pixels + strips +TRT→particle ID (e/π))
B=2T , $\sigma/p_T \sim 4\text{x}10\text{-}4\ p_T \oplus 0.01$
(e.g. H → bb)

Muon system: (precision chambers + triggers in air core toroids B=0.5T mean value) ,
σ/pT ~ 7 % at 1 TeV standalone
(e.g. H,A→μμ, H→4μ)

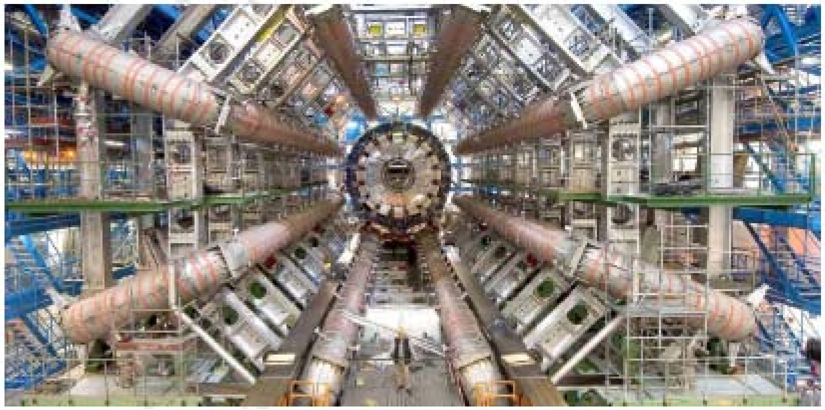
Hadronic Calorimeters: (Fe scint Cu-liquid argon)
$\sigma/E \sim 50\%/\sqrt{E} \oplus 0.03$
Jet, E_{Tmiss} performance **(e.g. H →ττ, H→bb)**

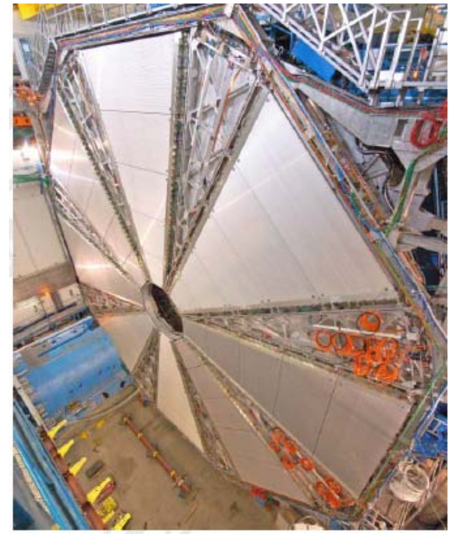
Electromagnetic Calorimeters: (Pb liquid argon)
$\sigma/E \sim 10\%/\sqrt{E}$, Uniform longitudinal segmentation
Provides: e/γ identification, energy and angular resolution, γ/jet , γ /π0 separation **(e.g. H→γγ)**

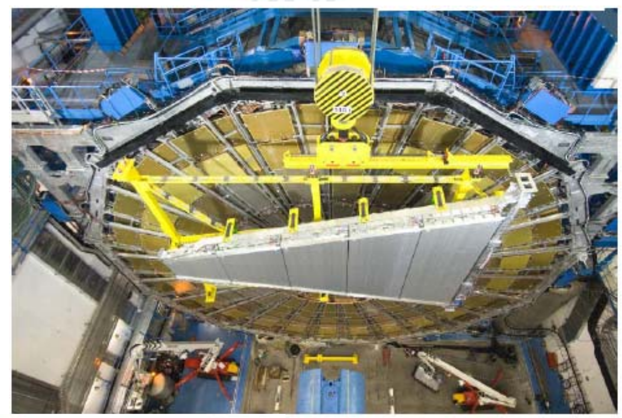
Energy-scale: e/γ~0.1%, μ~0.1%, Jets~1%

Commissioning the ATLAS detector

- A small collection of pictures…







SM Higgs searches

SM Higgs searches divided to three categories :

- Benchmark channels for detector performance studies
    - $H \rightarrow \gamma\gamma$
    - $H \rightarrow 4l$
- Counting experiments
    - $H \rightarrow WW(*)$
- Vector Boson Fusion channels
    - $H \rightarrow WW(*)$, $\tau\tau$

Accessibility of different H decay modes:

- For low mass H $m_H<2m_Z$
    - bb dominant but background huge, only ttH channel accessible one
    - also accessible $H\rightarrow\tau\tau$, $H\rightarrow ZZ^*\rightarrow 4l$, $H\rightarrow WW^*\rightarrow l\nu l\nu$, $H\rightarrow\gamma\gamma$
- For $m_H> 2m_Z$
    - $H\rightarrow ZZ\rightarrow 4l$, WW modes

H→γγ searches / Benchmark channel for detector performance

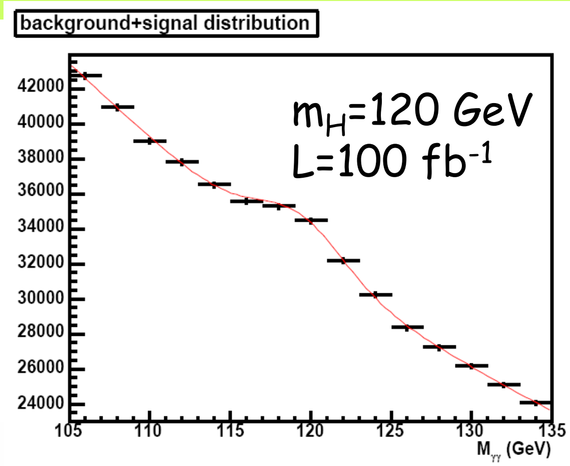
Characteristics: Narrow peak over smooth background

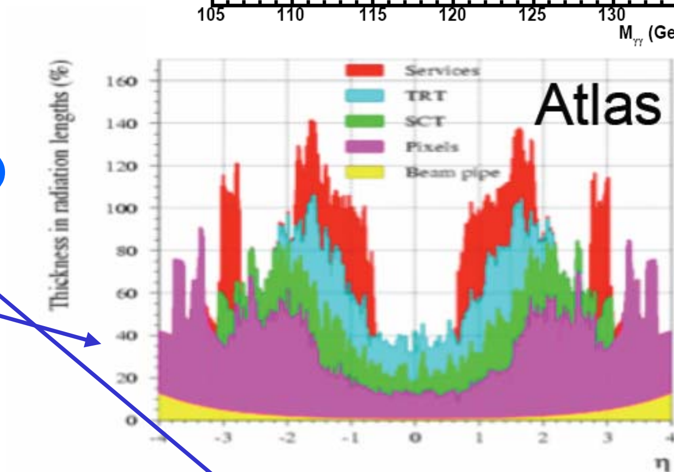
- Interesting channel in the H mass region 100-140 GeV

Backgrounds: irreducible γγ continuum, reducible jj, γj
With one or both misidentified jets as γ

Key points:

- energy resolution of em calorimeter and primary vertex determination
  - Mass resolution ~1%
- γ id to reduce jet background at true γ level by:
  - **High γ/π^0 separation ,isolation criteria**
  - **recovery of converted photons (~40% of events)**
- powerful jet rejection
  - ($>10^3$) for 80% γ efficiency



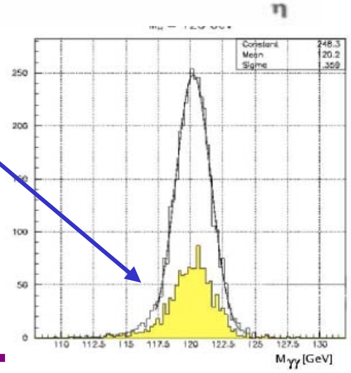


Recent developments: γγ background computed at NLO (agrees with Tevatron data) ; allows for signal to be computed at NLO level.

*Analysis improvements: -*Add of new discriminating variables (Pt of diphotons, angular distribution)

- Divide the events according to their production mode

Most powerful channel at low mass region ~6σ at L=30 fb^{-1}



H→4 leptons searches/ Benchmark channel for detector performance

Characteristics: Narrow peak over a small background

Key points: e/μ identification, energy resolution

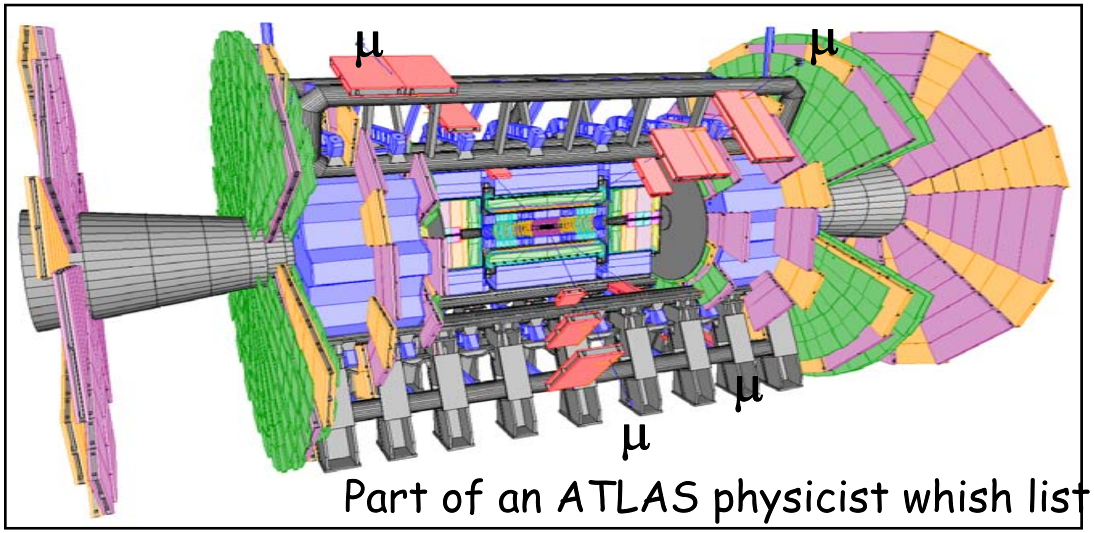
- Mass resolution 1.5-2 GeV dominated by detector resolution

Main backgrounds:

- reducible: Zbb→4l, tt →4l
  - Reduced by isolation criteria, impact parameter cuts
- irreducible: ZZ known at NLO, 20% added to account for gg→ZZ

Very clean signature but with low statistics

- small cross section (e.g σ x BR(H→4l) ~3-11 fb for m_H=130-200 GeV)



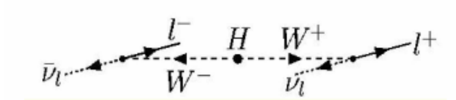
Part of an ATLAS physicist whish list

H→ WW*

Characteristics: Interesting channel in mass region ~160 GeV where BR (H→WW) >95%

No mass reconstruction, counting experiment

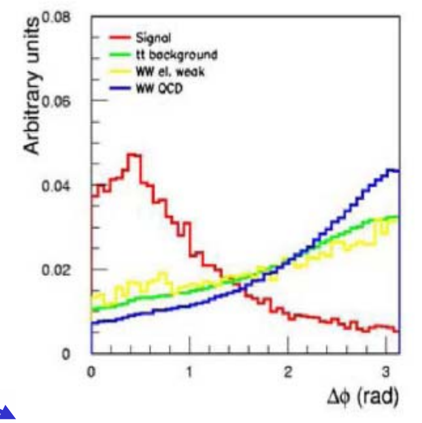
Look for dilepton final states (ee,e*μ*, *μμ*)



Backgrounds: tt rejected by jet-veto,

WW continuum rejected by lepton spin correlations

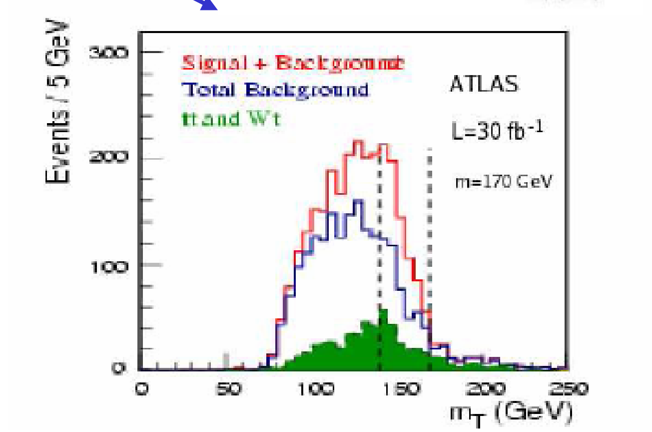
$$m_T = \sqrt{2 p_T^{\ell\ell} \not{E}_T (1 - \cos\Delta\phi)}$$



Difficulties: No mass peak,

needs accurate estimate of the background rate ;

use of control regions to estimate backgrounds and extrapolate to signal



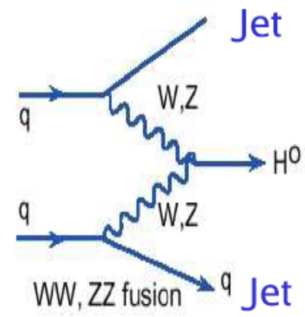
Recent developments:

gg→WW continuum contribution included

include tt and single top backgrounds @ NLO

VBF channels

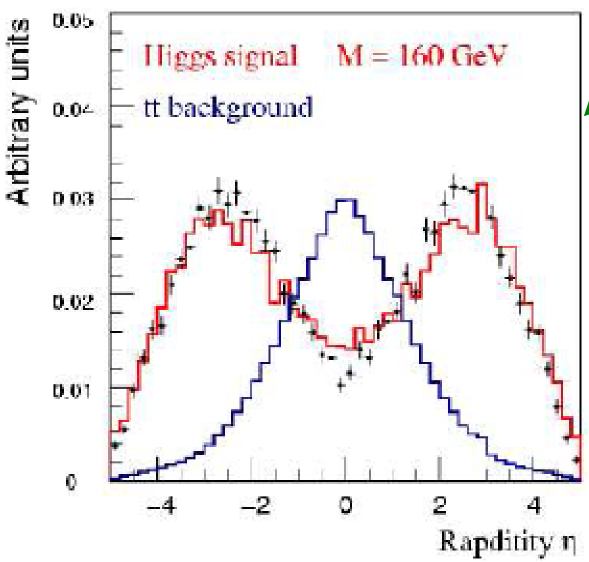
Characteristics: Topology of the events with no central jets and H decay products between the jets



Main decay modes: H→WW, ττ with at least one of W/τ decaying leptonically
τ reconstruction increases the sensitivity

Backgrounds: tt,Wt, WW+jets, γ/Z*+jets

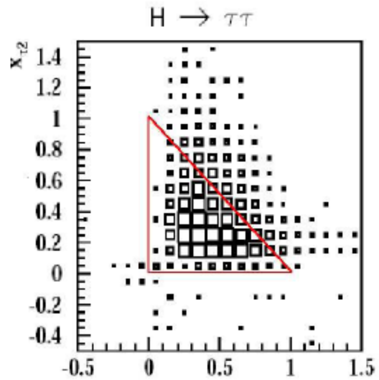
Selection criteria: Based on jet tagging: Apply central jet veto, ask for large rapidity difference between the tagged jets



VBF Analyses on H→WW(*), ττ channels showed:
- increase of discovery potential of WW(*) channel
- sensitivity to H→ ττ decays in the low mass region ~120 GeV

VBF H→ττ channel

Selection criteria: Tagging jets +H decay between jets

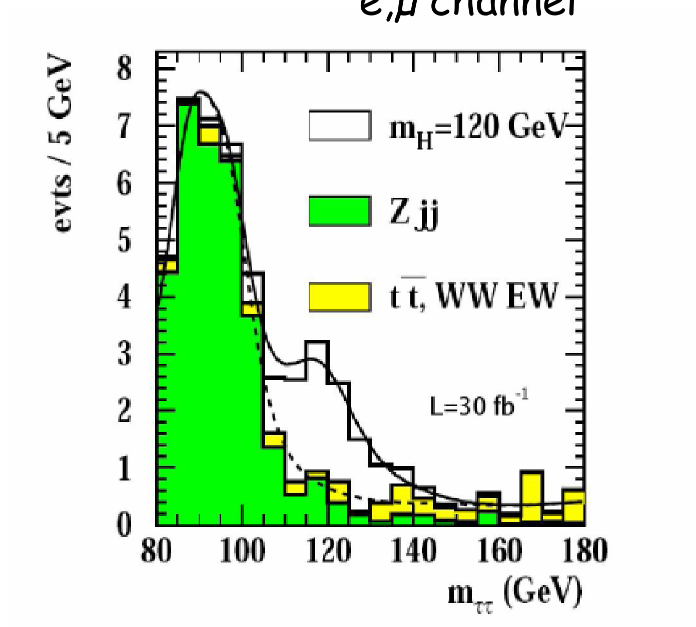


use of collinear approximation fo
mass reconstruction
(assume: l,v from taus collinear, $x_{\tau 1}$, $x_{\tau 2}$
visible fraction of energy,
missing Pt comes from the neutrinos)

Backgrounds: mainly Z→ττ + 2jets

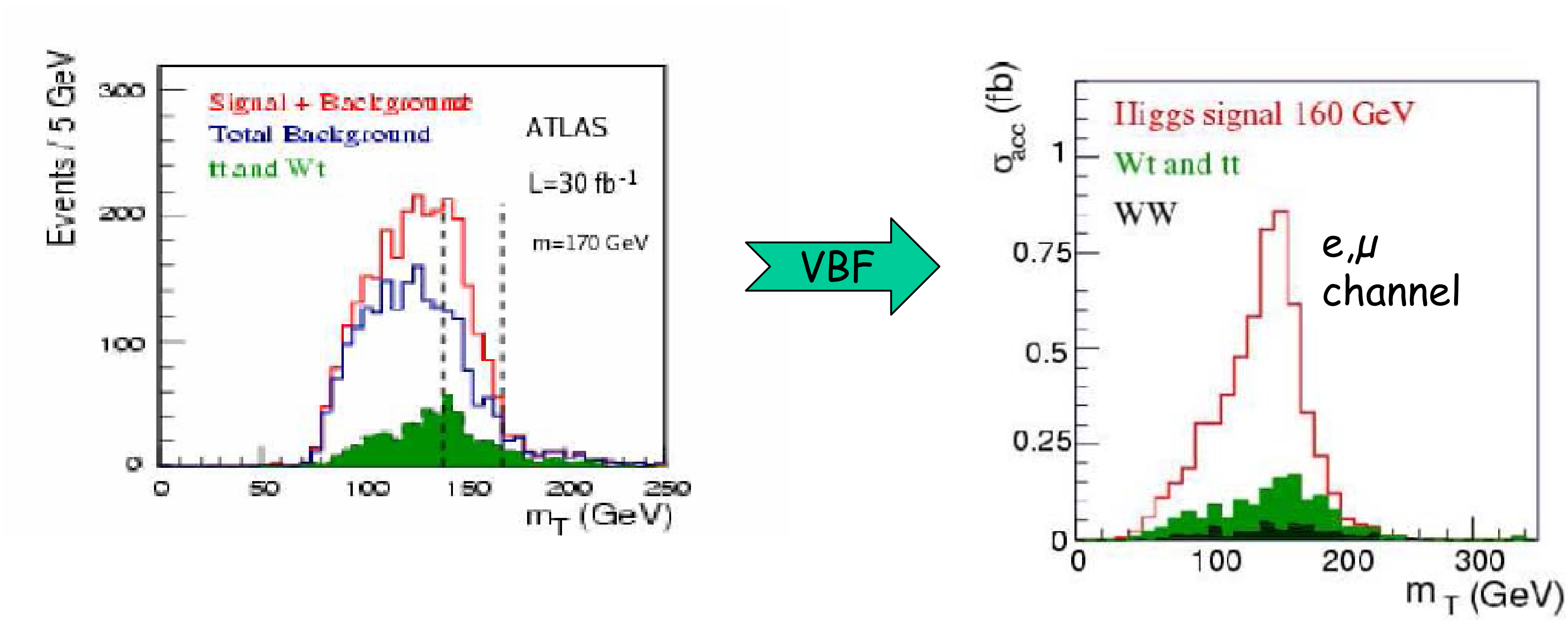
Resolution: Limited by Missing $_{ET}$ resolution (10 - 13 GeV)

e,μ channel



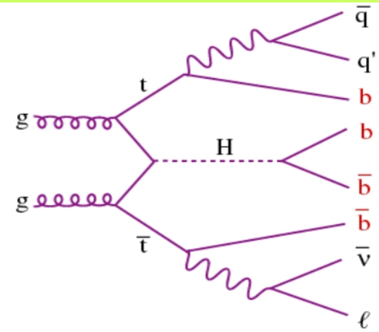
VBF H→ WW* channel

Use also of lepton spin correlations to enhance the signal



Increase of signal/background ration in the VBF channel by ~3.6

ttH, H→bb channel



Characteristics: Look at semileptonic decays of one top quark to allow for trigger

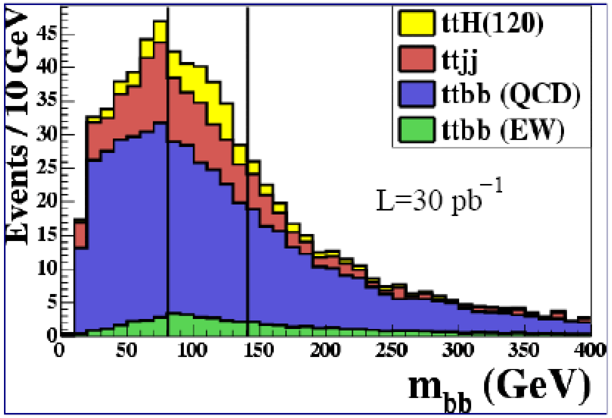
Topology with high jet multiplicity

Backrounds: 1. tt(+jj) b-tagging must be optimised for light jet rejection

2. WWbbjj, Wjjjjjj can be rejected by tt reconstruction

3. ttbb (EW/QCD) small differences in kinematic properties w.r.t ttH inserted in a likelihood function to allow for rejection

Selection cuts: Reconstruction of 6 jets, 4 b-tagged, reconstruction of tt pairs



Recent findings: ATLAS (and CMS) results more pessimistic than at TDR

Under investigation

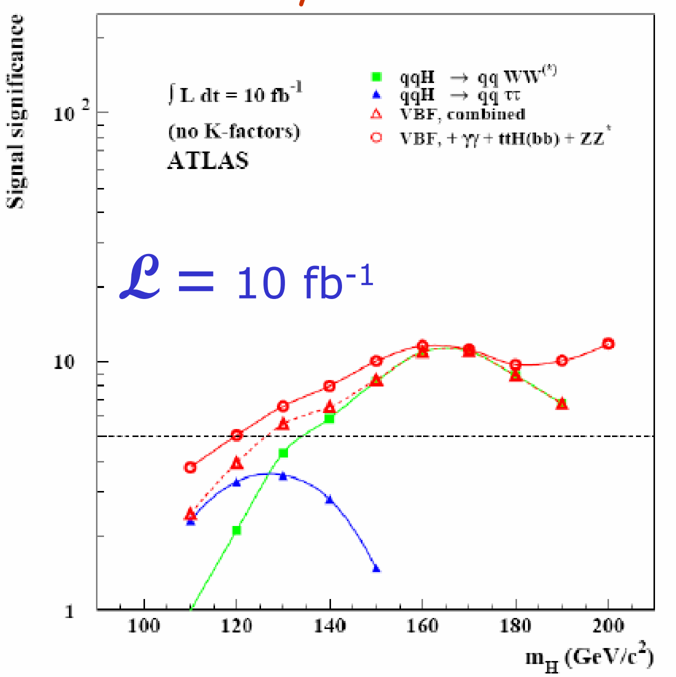
- smaller cross-sections
- systematics on b-tagging, jet resolution included

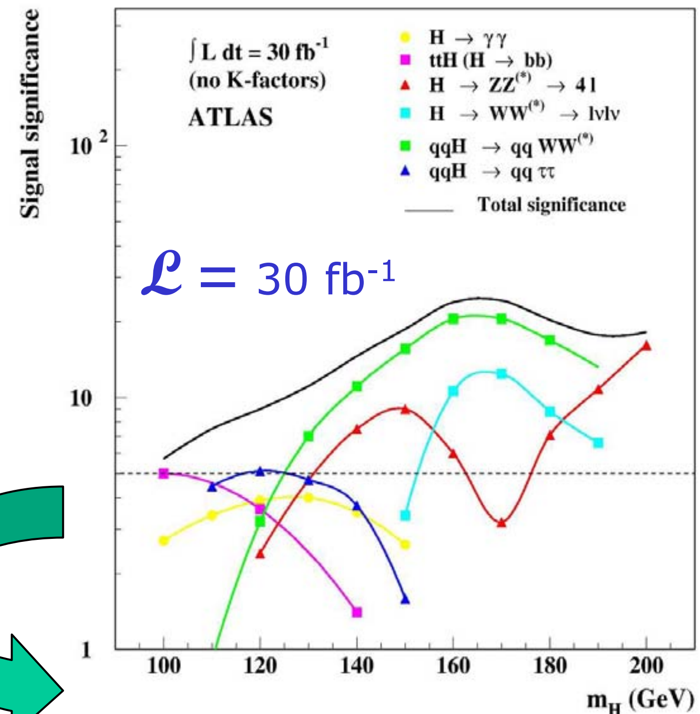
Combined sensitivity for a light SM Higgs

General remarks: 1. Absence of NLO cross sections in the following plots
2. Studies in some channels ongoing
- New sensitivity
- Full simulation with new MC generators

- Both VBF channels H→WW, ττ sensitive to low mass Higgs
- By combining all the channels: gg→H with H→γγ, 4l , qqH with H→ ττ, WW(*), ttH, with H→bb, ττ

A 5σ discovery could be reached for mH>120 GeV





Atlas potential for a light SM Higgs with L=30 fb -1
Several channels can be combined at mH~115 GeV

Background systematics: the key issue

G. Unal
Physics at LHC
Cracow, July 2006

Background systematics and how to normalize bkg from data

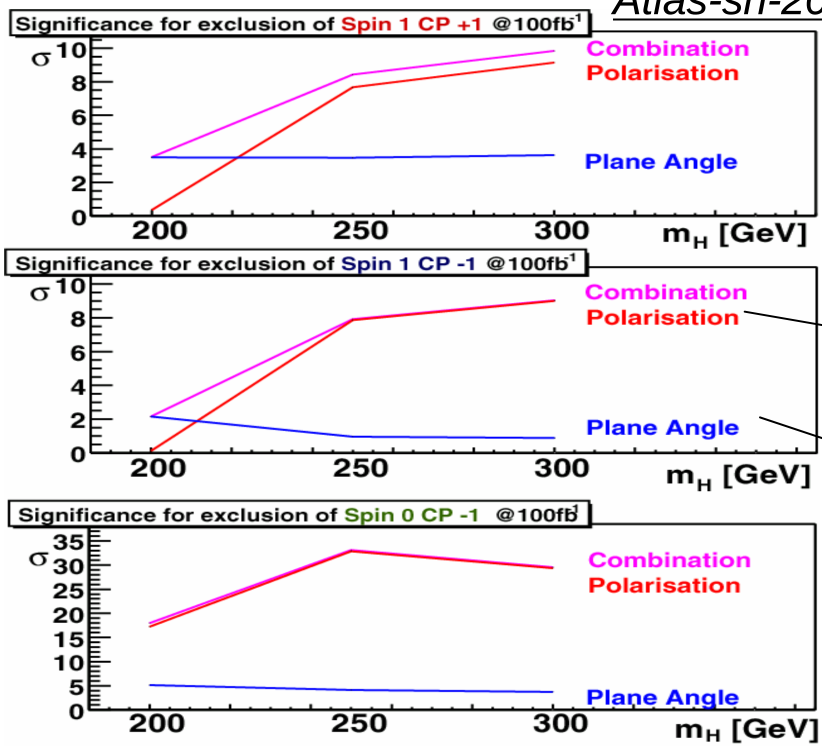
Channel	Main background	S/B	Bkg. sys for 5σ	Proposed technique/comments
$H \to \gamma\gamma$	Irreduc. $\gamma\gamma$ Reducible $q\gamma$	3-5%	0.8%	Side-bands (bkg shape not known a priori)
ttH H->bb	ttbb	30%	6%	Mass side-bands Anti b-tagged ttjj ev.
H->ZZ*-> 4 lep	ZZ->4l Reducible tt, Zbb	300-600%	60%	Mass side-bands Stat Err <30% 30fb^{-1}
$H \to WW^* \to ll\nu\nu$	WW*, tW	30-150%	6-30%	No mass peak Bkg control region and extrapolation
VBF channels In general	Rejection QCD/EW	Study forward jet tag and central jet veto		Use EW ZZ and WW QCD Z/W + jets
VFB H->WW	tt, WW, Wt	50-200%	10%	Study Z,W,WW and tt plus jets
VBF $H \to \tau\tau$	Zjj, tt	50-200%	10-40%	Mass side-bands Beware of resolution tails

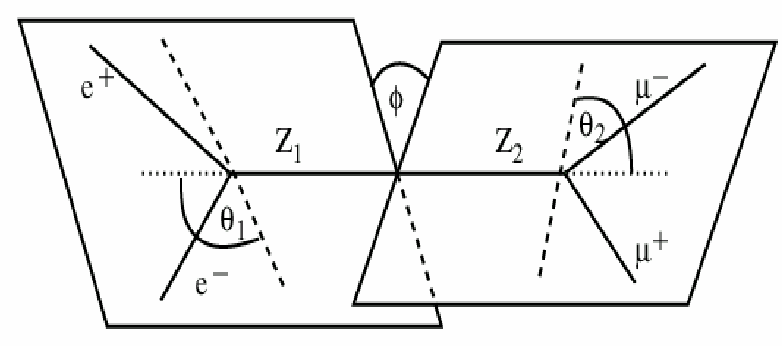
Higgs properties

To define Higgs properties (mass, coupling, spin) more luminosity than ~30 fb-1 is needed (a few examples given below)

- Higgs spin (CP):
  - If we observe the process gg→H or H→γγ then spin 1 is excluded
  - For M_H>200 GeV, study spin/CP from H→ZZ→4l
  - Exclusion can be deduced from θ and φ distributions

Atlas-sn-2003-025





Θ → polar angle of the decay leptons relative to the Z

Φ → angle between the decay plane of the two Zs

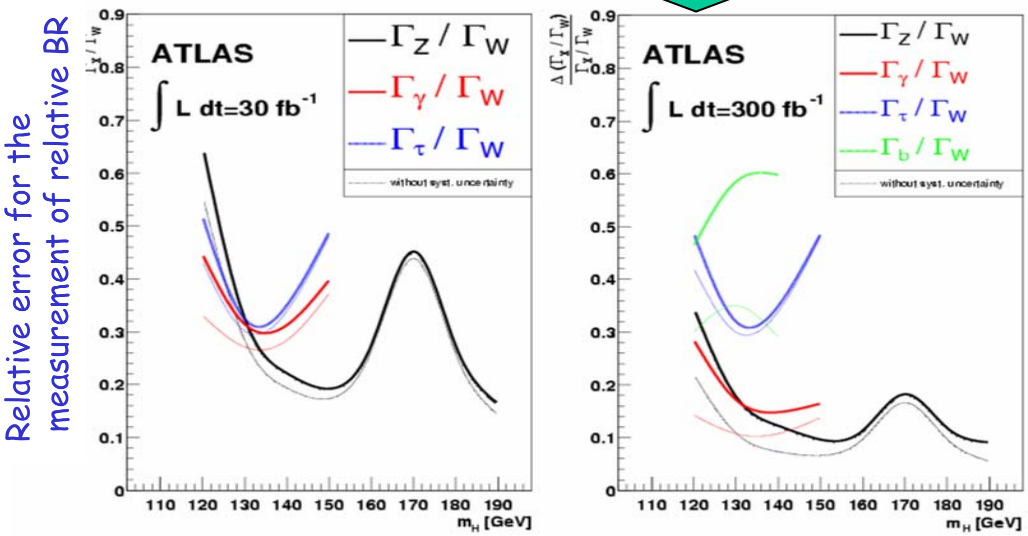
Higgs properties

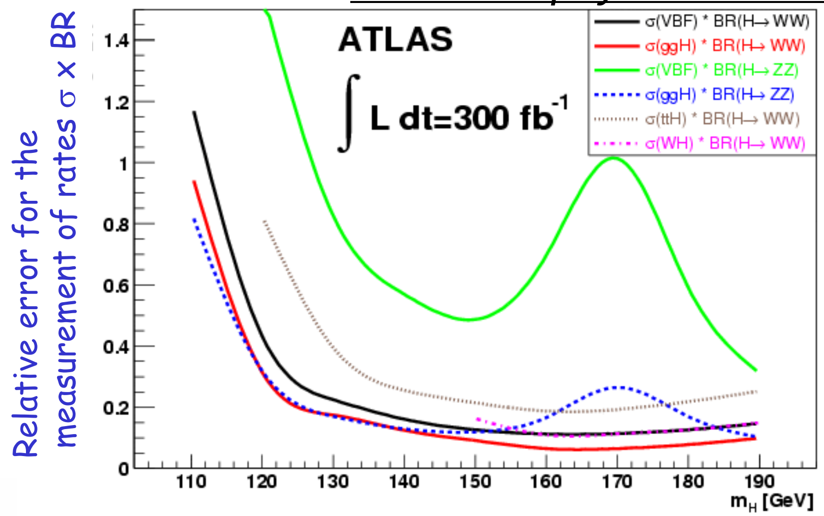
Higgs couplings: Concentrate on low m_H scenario and define 3 steps:

Atlas note phys-2003-030

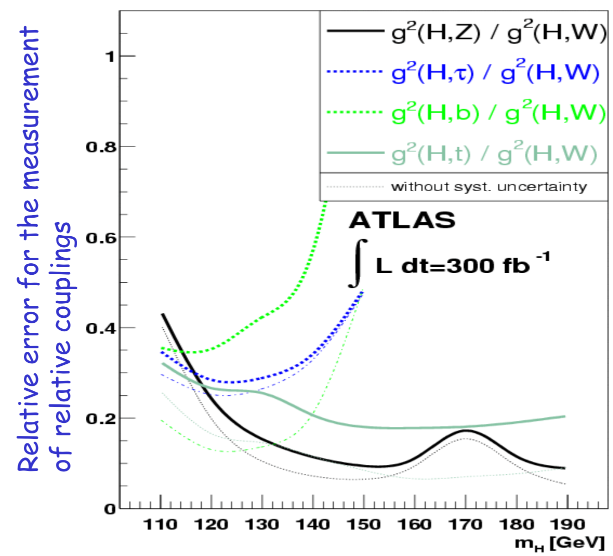
1st step: assume spin 0 and measure $\sigma \times$ BR in different channels

2nd step: assume only one H and measure the ratio of BRs





3rd step: assume no new particles on the loop, no strong coupling to light fermions and express rates and BR as a function of 5 couplings $g_W, g_Z, g_{top}, g_b, g_\tau$



like for example:

$\sigma(\text{VBF})$: $a_{WF} . g_W^2 + a_{ZF} . g_Z^2$

$\text{BR}(\gamma\gamma)$: $(b_1 . g_W^2 - b_2 . g_{top}^2)/\Gamma_H$

MSSM Higgs searches

Phenomenology:

- 2 Higgs doublets with 5 physical states: h,H,A,H±
- Higgs sector described by 4 masses and 2mixing angles β and α
- At leading order
  - 2 independent parameters (usually use of: **M_A, tanβ**)
  - hierarchy of mass $m_h < m_Z$
- Couplings $g_{MSSM} = \xi\, g_{SM}$
  - no coupling of A to W/Z
  - large BR(h,H,A→ττ, bb) for large tanβ
- Large loop corrections on masses and couplings
  - Parameters $M_{top}, X_t, M_{SUSY}, M_2, \mu, M_{gluino}$
  - Radiative corrections increase upper bound on m_h ~135 GeV

ξ	t	b/τ	W/Z
h	$\cos\alpha/\sin\beta$	$-\sin\alpha/\cos\beta$	$\sin(\alpha-\beta)$
H	$\sin\alpha/\sin\beta$	$\cos\alpha/\cos\beta$	$\cos(\alpha-\beta)$
A	$\cot\beta$	$\tan\beta$	-----

α mixing angle between h H
expressed in terms of M_A ,tanβ

Strategy for exclusion bounds and discovery potential:

- Choose specific parameter points: benchmark scenarios

Mhmax scenario: maximal M_h when Higgs-stop mixing large
No mixing scenario: stop mixing set to 0
Gluophobic scenario: coupling of h to gluons suppressed
designed for gg→h, h→γγ, h→ZZ→4l
Small α scenario: coupling of h to b(τ) suppressed
designed for VBF, h→ττ and tth,h→bb

- **Scan (M_A, tanβ)** plane after fixing the 5 parameters in benchmark scenarios

Name	M_{SUSY} (GeV)	μ (GeV)	M_2 (GeV)	X_t (GeV)	M_{gluino} (GeV)
m_h-max	1000	200	200	2000	800
no mixing	2000	200	200	0	800
gluophobic	350	300	300	-750	500
small α	800	2000	500	-1100	500

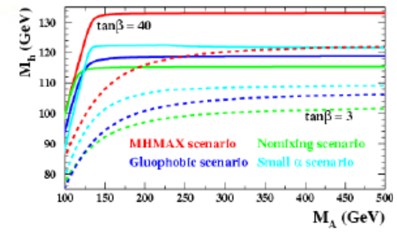
Strategy for the searches:

Apply SM searches
Apply direct searches of H/A decaying to SM particles
Direct searches of H ±

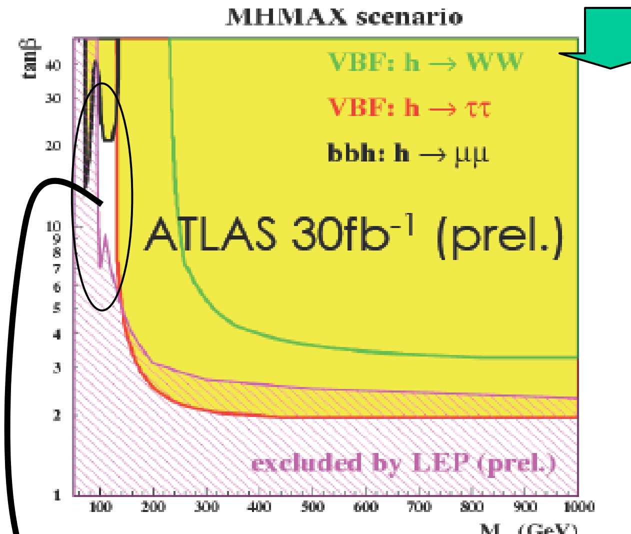
MSSM Higgs searches/ Light Higgs boson at 30 fb^{-1}

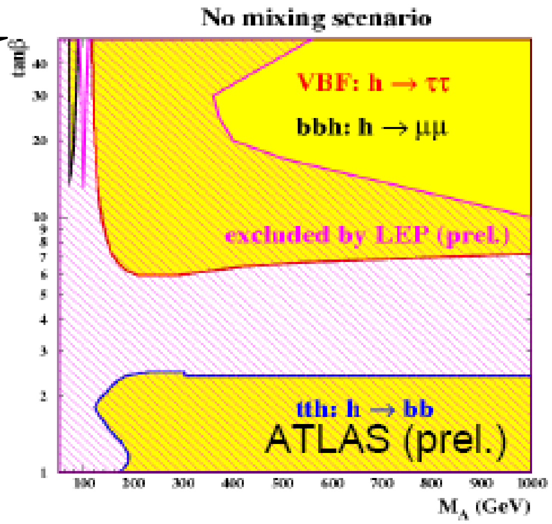
Light neutral Higgs h: Is it observable over all parameter space?

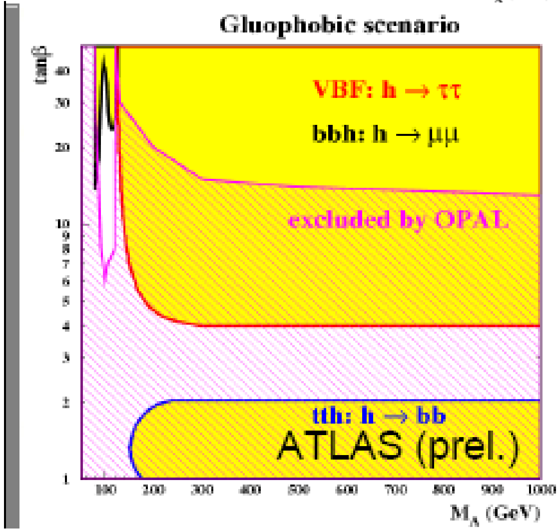
- most important channels VBF
- differences between scenarios mainly due to M_h

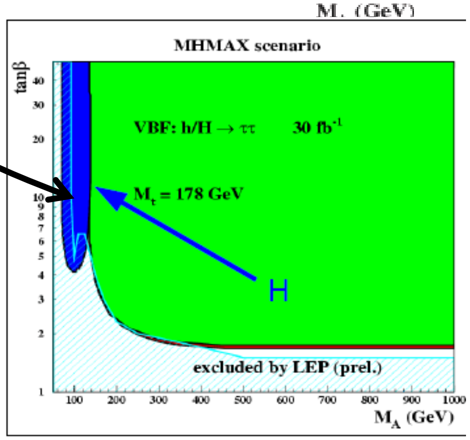


almost entire plane (**M_A, tanβ**) covered



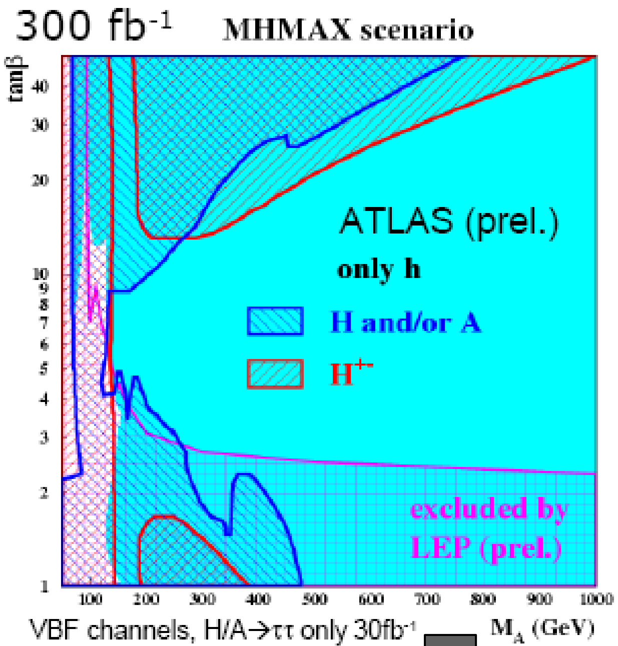






The whole at low M_A 90-100 GeV
-(h unobservable for all scenarios)
can be covered by the H→ττ searches
-(H observable)

MSSM Higgs searches/overall discovery potential ($300\ fb^{-1}$)



Some remarks from this plot

- In the whole parameter space at least 1 Higgs boson is observable
  - in some parts >1 Higgs bosons observable
- But large area in which only one Higgs boson observable

Basic question: Could we distinguish between SM and MSSM Higgs sector
- e.g via rate measurements?

Result assuming no H→SUSY
- *On going studies to include Susy decays of Higgs bosons e.g* $H^{\pm} \to \chi^{\pm}_{1,2}\chi^{0}_{1,2,3,4} \to 3l + E_T^{miss}$

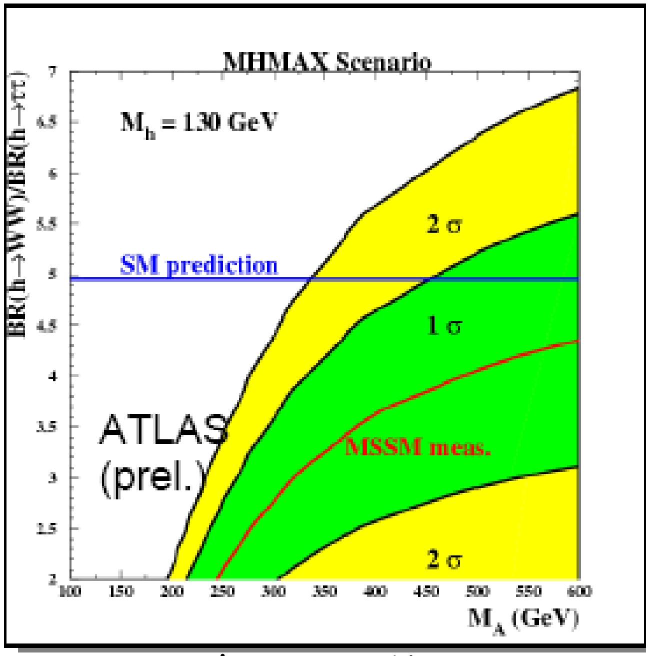
MSSM Higgs searches/distinguish between SM and MSSM Higgs sector

Basic question: Could we distinguish between SM and MSSM Higgs sector (e.g via rate measurements?)

Method: - Looking at VBF channels (30 fb^{-1}) and estimate the sensitivity from rate (R) measurements

- Compare expected rate R in MSSM with prediction from SM

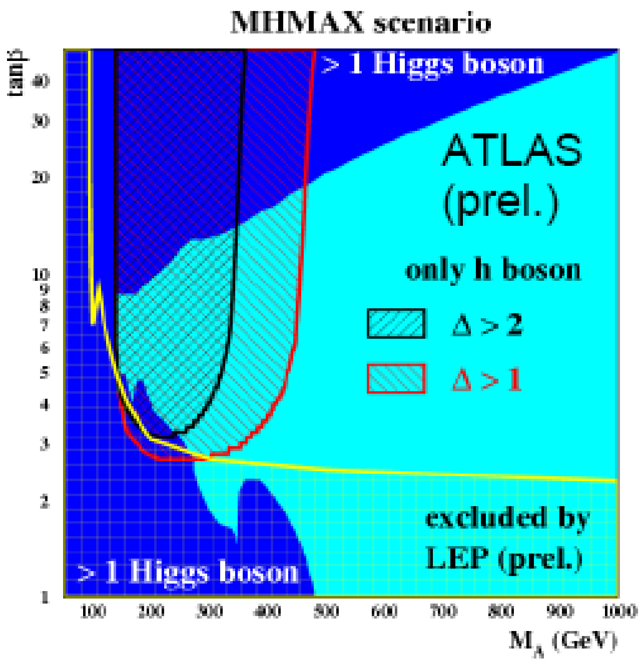
$$R = \frac{BR(h \to WW)}{BR(h \to \tau\tau)}$$



Assuming knowing M_h mass precisely
No systematic errors included

$$\Delta = |R_{MSSM} - R_{SM}| / \sigma_{exp}$$

σ_{exp} = expected error on the ratio in the particular MSSM parameter space



No systematic errors included
(study ongoing)

Summary / Conclusions

Detailed studies of many SM /MSSM Higgs searches have been performed with ATLAS detector

SM searches:

- Good sensitivity can be reached already with~10 fb^{-1}
  - only if we control properly the detector performance and background shapes. Only the real data will tell us that
- If Higgs is there, detailed studies of its properties require more statistics

MSSM searches:

- The whole MSSM parameter space is covered by at least one Higgs boson
  - Systematic error evaluation ongoing
- Large parameter space in which only one Higgs boson observable
  - Studies to include SUSY decays of Higgs ongoing
  - Work is needed to distinguish between SM and MSSM sector in this case

ATLAS detector is being commissioned. We expect the first data (other than cosmics) in less than 1 year from now.

- Exciting times are on the way…
  - What will we have to do with the first fb^{-1} ?
    - Only a few highlights in the following 3 slides…

Acknowledgments:
D. Cavalli, L. Fayard, L. Feligioni,
A. Kaczmarska, S. Paganis,
M. Schumacher, G. Unal, L. Vacavant

What we will do with the first data at √s=14 TeV

Detector performance calibration and alignment

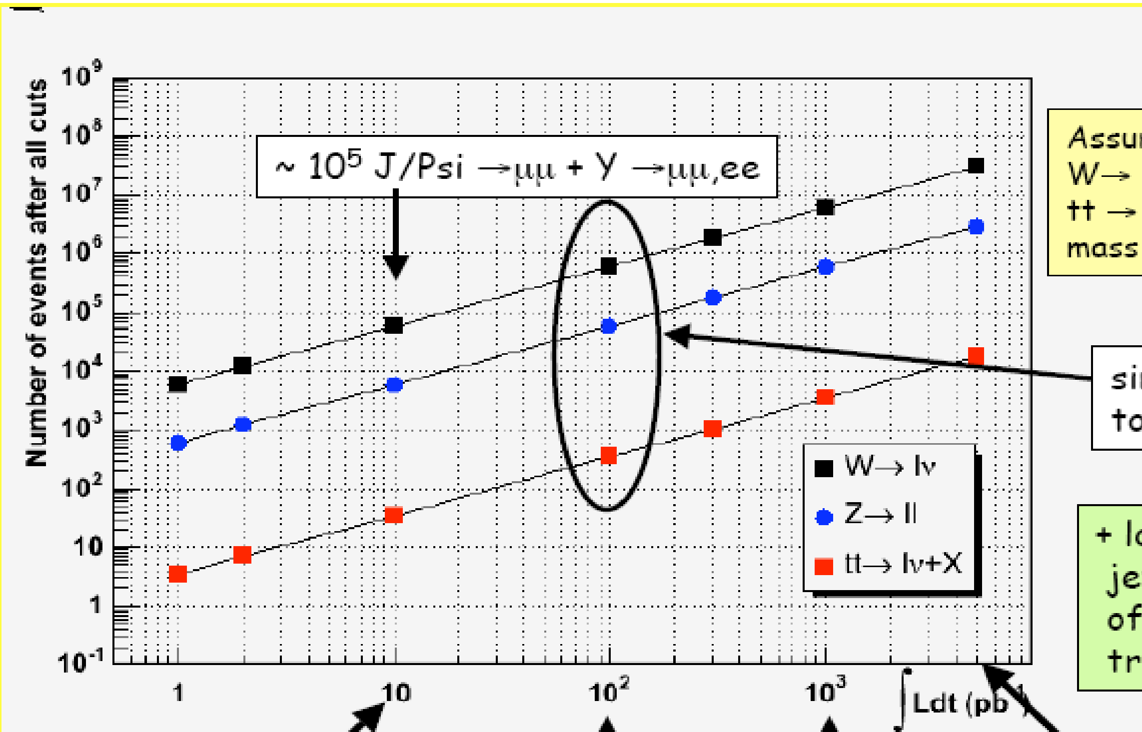
- Common strategy to all sub-systems
- Use of Z,W,top for most of the studies
  - Fortunately LHC is a Z,W,top factory !

- For calorimeter calibration
  - J/ψ ->e^+e^- and Z->e^+e^- for electromagnetic calorimeter
  - Z->l+l- γ mass constraint to set γ energy scale
  - W->jj from Top and Z/γ + 1 jet events Jet Energy Scale
  - Z→νν、W→lν Missing ET calibration
- For momentum calibration
  - J/ψ -> $\mu^+\mu^-$ and Z->$\mu^+\mu^-$ for Muon momentum
- To Determine E/P matching
  - Isolated tracks (W->lν, **t** decay)
- b-jet tagging efficiency
  - tt events

Precision we expect to have in the beginning		Desired precision
Inner tracking alignment 20-200 μm	→	10 μm
e/m calo Uniformity ~1% e/γ scale ~1-2 %		7‰(unif) 1‰ (scale)
Jet Energy Scale ~10%		1 %

Number of events at the first 10-100 pb^{-1} of LHC

How many events per experiment at the beginning ?



l ≡ e or μ

Assumed selection efficiency:
W→ lν, Z→ ll : 20%
tt → lν+X : 1.5% (no b-tag, inside mass bin)

similar statistics to CDF, D0 today

+ lots of minimum-bias and jets (10^7 events in 2 weeks of data taking if 20% of trigger bandwidth allocated)

$10\ pb^{-1}$ ≡ 1 month at 10^{30} and < 2 weeks at 10^{31}, ε=50%

$100\ pb^{-1}$ ≡ few days at 10^{32} , ε=50%

$1\ fb^{-1}$ ≡ 6 month at 10^{32}, ε=50%

$5\ fb^{-1}$ ≡ 3 month at 10^{32} and 3 month at 10^{33}, ε=50%

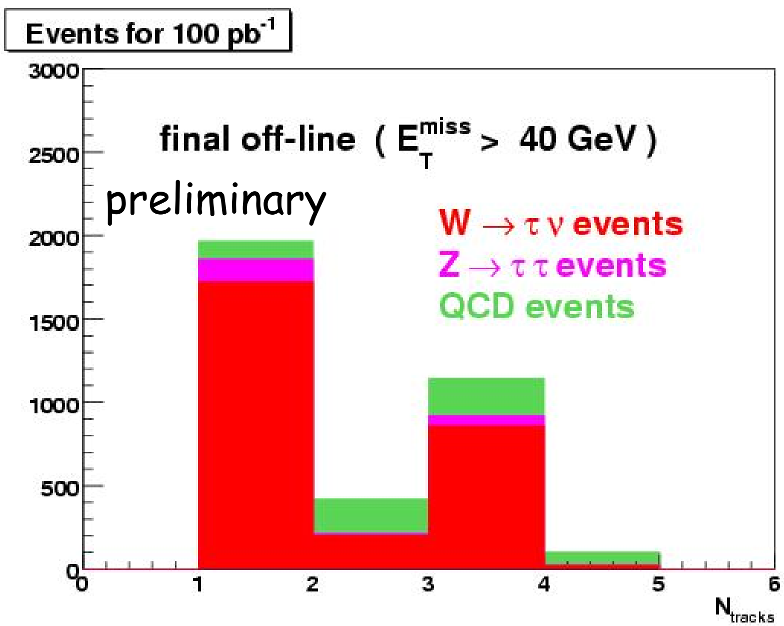
Examples of analyses

Z,W production at 10-100 pb^{-1} :

Extract the τ signal provided an efficient E_T^{miss} and τ trigger

Expected rates for 100 pb^{-1}	$W \to \tau\nu$, $\tau \to$hadron	$W \to e\nu$	$Z \to \tau\tau$, $1\tau \to$hadron
σ.B (pb)	11200	17300	1500
τ30i + xE35	~ 15 000	~ 250 000	~ 1300
τ20i + xE25	~ 60 000	~ 560 000	~ 3500

Assuming eff ~ 80% for τ trigger, ~ 50% for τ reco/id

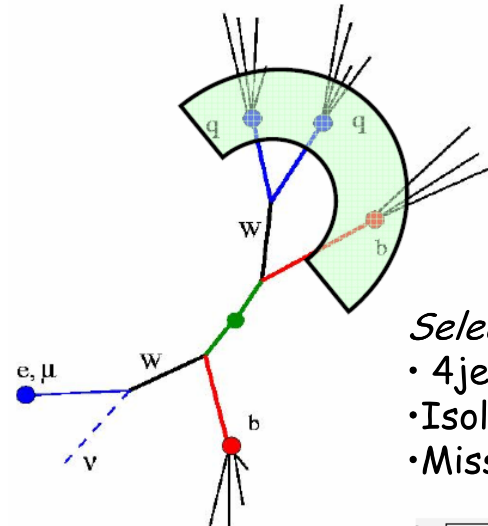


"counting" experiment: evidence in the N_{Track} spectrum.
Signal x 10 and bgd x 100 with respect to 2 TeV collisions.
Profit from low-luminosity operation to trigger at lowest possible thresholds (E_T τ15i), raise E_T^{miss} cut as luminosity goes up.
Require QCD jet rejection of 10^3- 10^4 at 50% efficiency and p_T ~ 20 GeV

Top measurements with < 1fb^{-1}

without b-tag

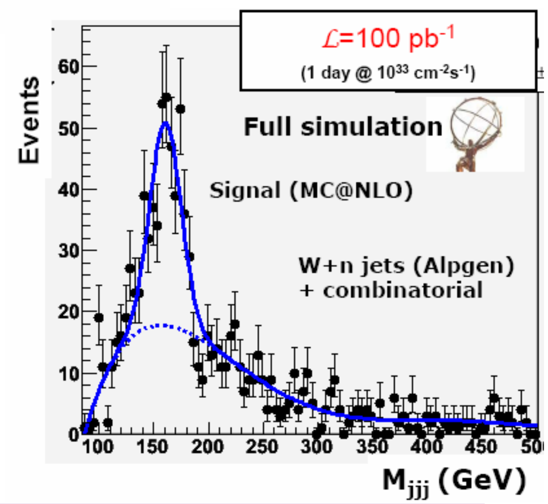
-Event topology: 3 jets with highest ΣP_T



Select events with:

- 4jets with P_T > 40 GeV
- Isolated lepton P_T > 20 GeV
- Missing E_T > 20 GeV

Top events will be used to calibrate the calorimeter jet scale (W→jj from t→bW)
With 30pb-1 data, Δm_{top} ~ 3.2 GeV
(sys. Error dominated: FSR,b-jet scale)



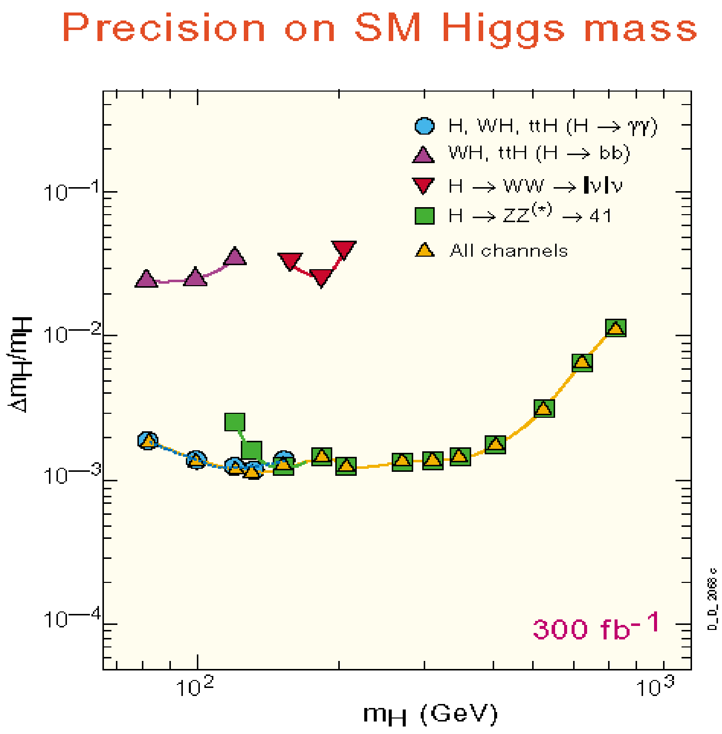
Backup slides

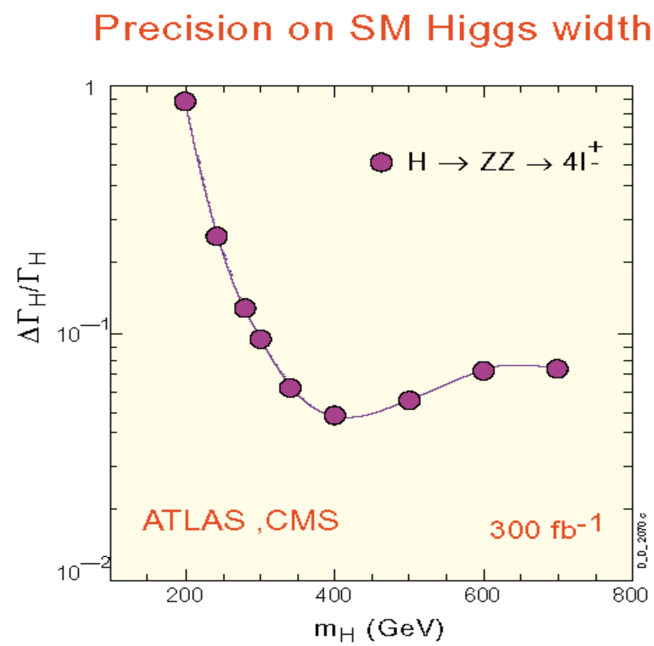
Higgs properties

To define Higgs properties (mass, coupling, spin) more luminosity than ~30 fb-1 is needed (a few examples given below)

- Higgs mass measurement :
  - Channels that can contibute H→$\gamma\gamma$, H→4leptons
  - also H→$\tau\tau$ at low luminosity

Width accessible only for mH>200 GeV





Particle ID capabilities of ATLAS detector

Look for example at A. Kaczmarska
talk at
Physics at LHC
Cracow, July 2006

- Particle identification capability of Atlas detector (e, γ, τ, b-tag, μ)
  - $\varepsilon(e) \sim 70\%$ Rej(jet) ~ few 10^5
  - $\varepsilon(\gamma) \sim 80\%$ Rej(jet) ~ 10^4
  - $\varepsilon(\tau) \sim 30\%$ Rej(jet) ~ 600-10 000
  - $\varepsilon(b) \sim 60\%$ Rej(u,d) ~ 500, Rej(c)~10
  - $\varepsilon(\mu) \sim 95\%$ fakes <1 %

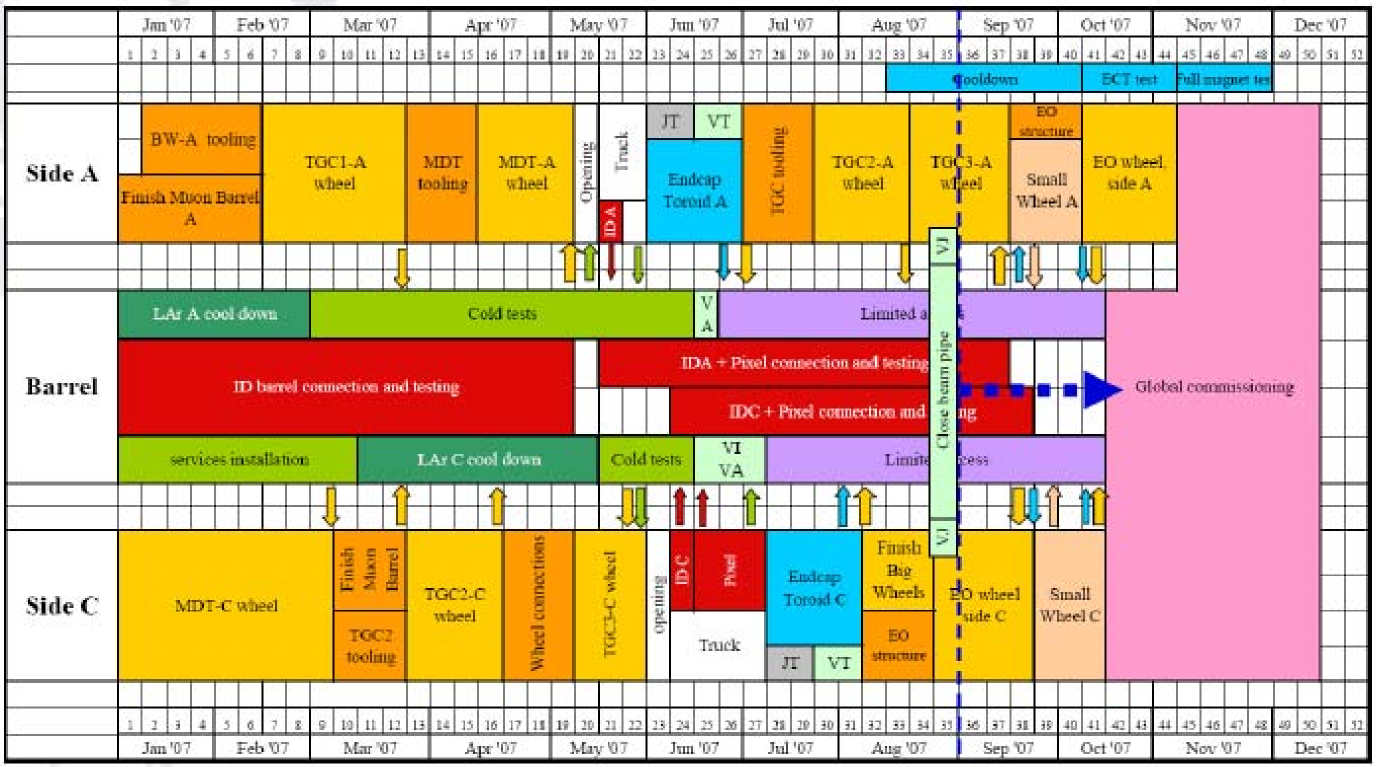
Commissioning the ATLAS detector

Endgame: Installation Schedule 2007

- If all goes well:

finish installing all sub-detector components before end of 2007

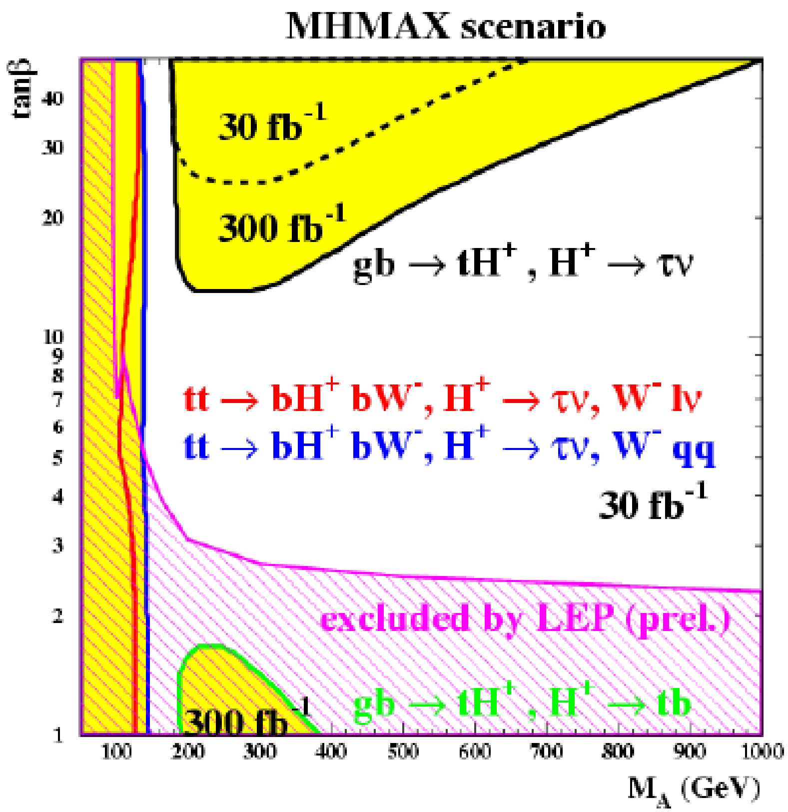
biggest/outermost (muon spectrometer endcaps) and smallest/innermost (pixel) detectors are last to be installed



ATLAS / CMS characteristics, performance

SYSTEMS	ATLAS	CMS
INNER TRACKER	Silicon pixels+ strips TRT → particle ID (e/π) B=2T $\sigma/p_T \sim 4x10^{-4}\ p_T \oplus 0.01$	Silicon pixels + strips No particle identification B=4T $s/p_T \sim 1.5x10^{-4}\ p_T \oplus 0.005$
EM CALO	Pb-liquid argon $\sigma/E \sim 10\%/\sqrt{E}$ Uniform longitudinal segmentation	$PbWO_4$ crystals $\sigma/E \sim 2.5\%\sqrt{E}$ no longitudinal segmentation
HAD CALO	Fe-scint. + Cu-liquid argon $\sigma/E \sim 50\%/\sqrt{E} \oplus 0.03$	Cu-scint. (> 5.8 l +catcher) $\sigma/E \sim 100\%/\sqrt{E} \oplus 0.05$
MUON SYSTEM	Air-core toroids $\sigma/pT \sim 7$ % at 1 TeV standalone	Fe → $\sigma/p_T \sim 5\%$ at 1 TeV combining with tracker
MAGNETS	Inner tracker in solenoid (2T) Calorimeters in field-free region Muon system in air-core toroids (4T at peak, 0.5 T mean value)	Solenoid 4T Calorimeters inside the field

MSSM searches / H±



Two different mass regions investigated
- Low mass : $M_{H\pm} < M_{top}$
 gg→tt, tt→$H^{\pm}$bWb→τvb lvb
 → τvb qqb
Only for low luminosity

-high mass: $M_{H\pm} > M_{top}$
gb→$H^{\pm}$t, H→ τv