Standard Model Higgs Boson Search at the Large Hadron Collider

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Anticipating Physics at the LHC, June 2nd – 6th , 2008, KITP, Santa Barbara

Outline

- Introduction
- Status of the Large Hadron Collider
- The ATLAS and CMS detectors at LHC
- New results from LHC on Higgs studies
- Conclusions

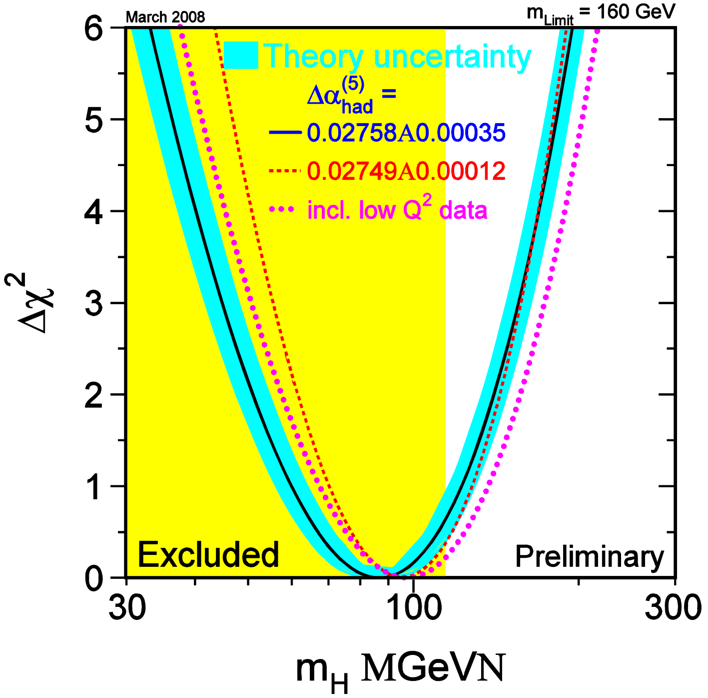
The Higgs Boson

“Revealing the physical mechanism that is responsible for the breaking of electroweak symmetry is one of the key problems in particle physics”

“A new collider, such as the LHC must have the potential to detect this particle, should it exist.”

Direct Searches

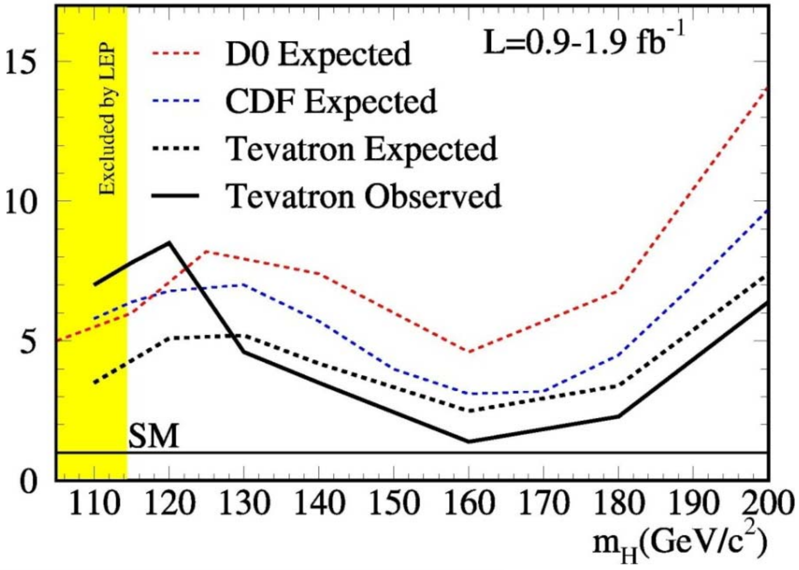
LEP m_H>114.4 GeV @95% CL



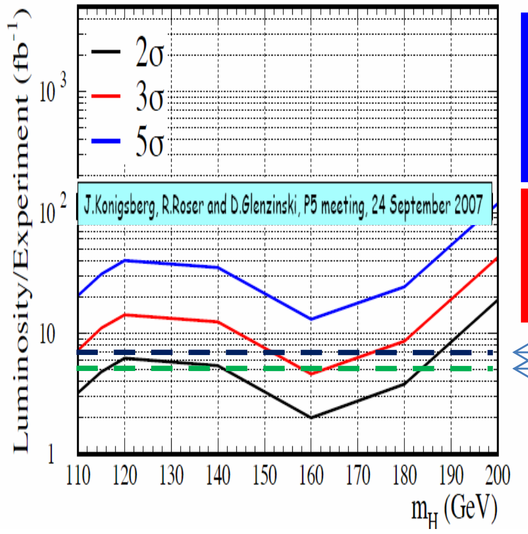
http://lepewwg.web.cern.ch/LEPEWWG/

Delta-chi2 curve derived from high-Q2 precision electroweak measurements, performed at LEP and by SLD, CDF, and D0, as a function of the Higgs-boson mass, assuming the Standard Model to be the correct theory of nature. The preferred value for its mass, corresponding to the minimum of the curve, is at 87 GeV, with an experimental uncertainty of +36 and -27 GeV (at 68 percent confidence level derived from Delta chi2 = 1 for the black line, thus not taking the theoretical uncertainty shown as the blue band into account).

The Higgs Boson



- Collected >3 fb^{-1}, expected 6 or 7 fb^{-1} by the end of 2009
- With 1.9 fb^{-1} analysis close to exclude wide range $M_H \approx 160$ GeV
- Sensitivity lower than expected in low M_H region

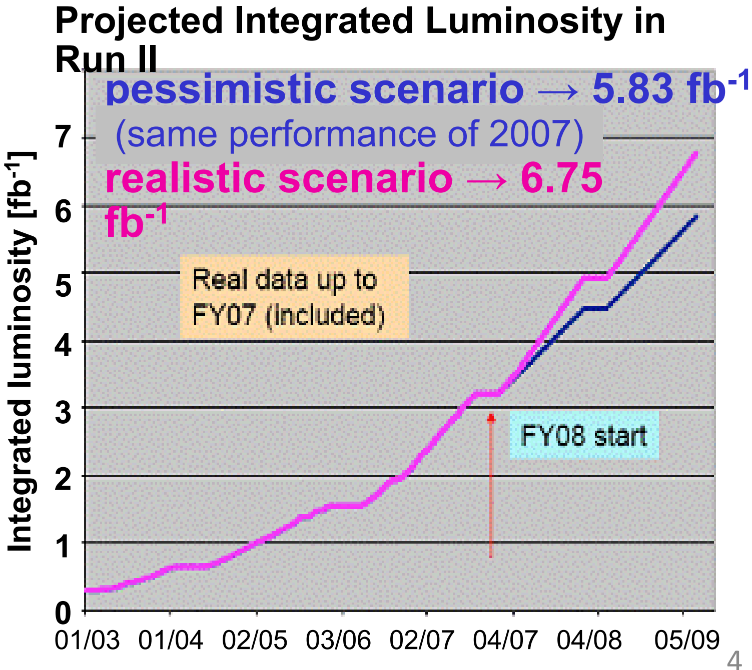


5.0
7.0

With 7 fb^{-1}
- exclude all masses !!!
- 3-sigma sensitivity 150:170

LHC's sweet spot

With 5.5 fb^{-1} tougher:
- Exclude 140:180 range
- 3-sigma in one point: 160

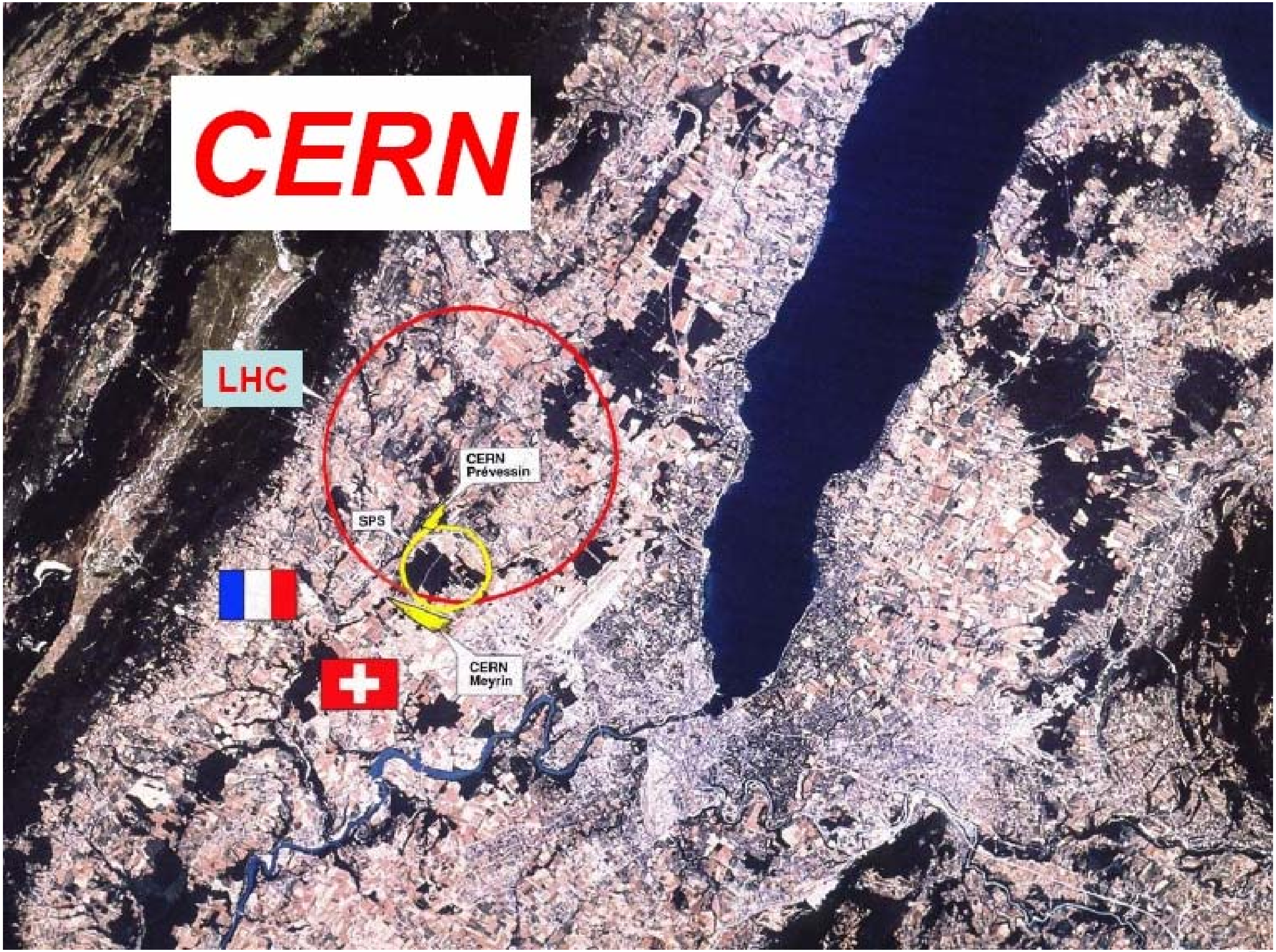


pessimistic scenario → 5.83 fb^{-1}

(same performance of 2007)

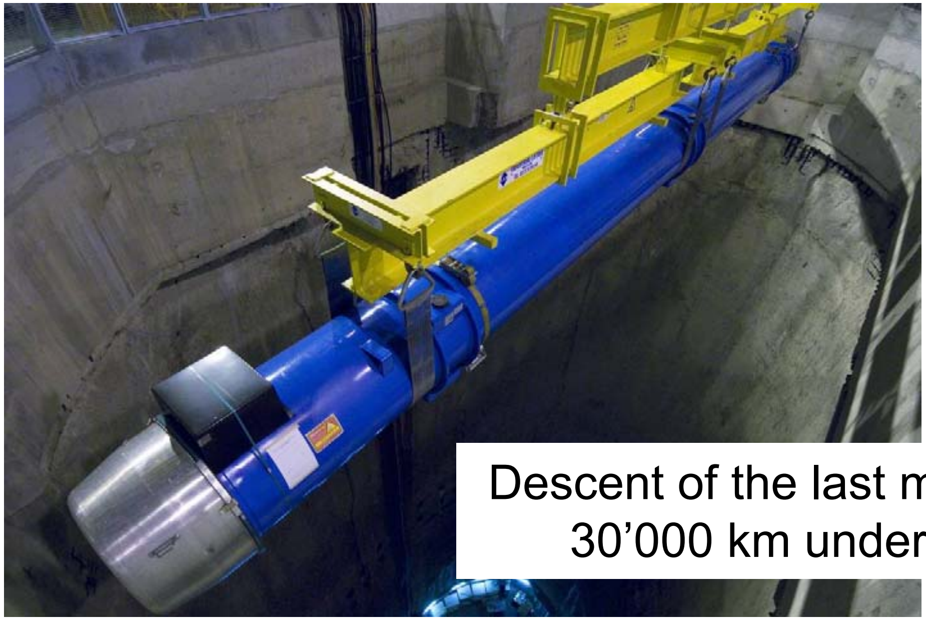
realistic scenario → 6.75 fb^{-1}

CERN



Status of the Large Hadron Collider

Nominal LHC parameters	
Beam energy (TeV)	7.0
Number of particles per bunch	1.15×10^{11}
Number of nunches per beam	2808
Stored beam energy (MJ)	362
Norm. transverse emittance (μm rad)	3.75
Bunch length (cm)	7.55
Luminosity ($cm^{-2}\ s^{-1}$)	1×10^{34}



Descent of the last magnet, 26 April 2007
30’000 km underground at 2 km/h

Status of the Large Hadron Collider

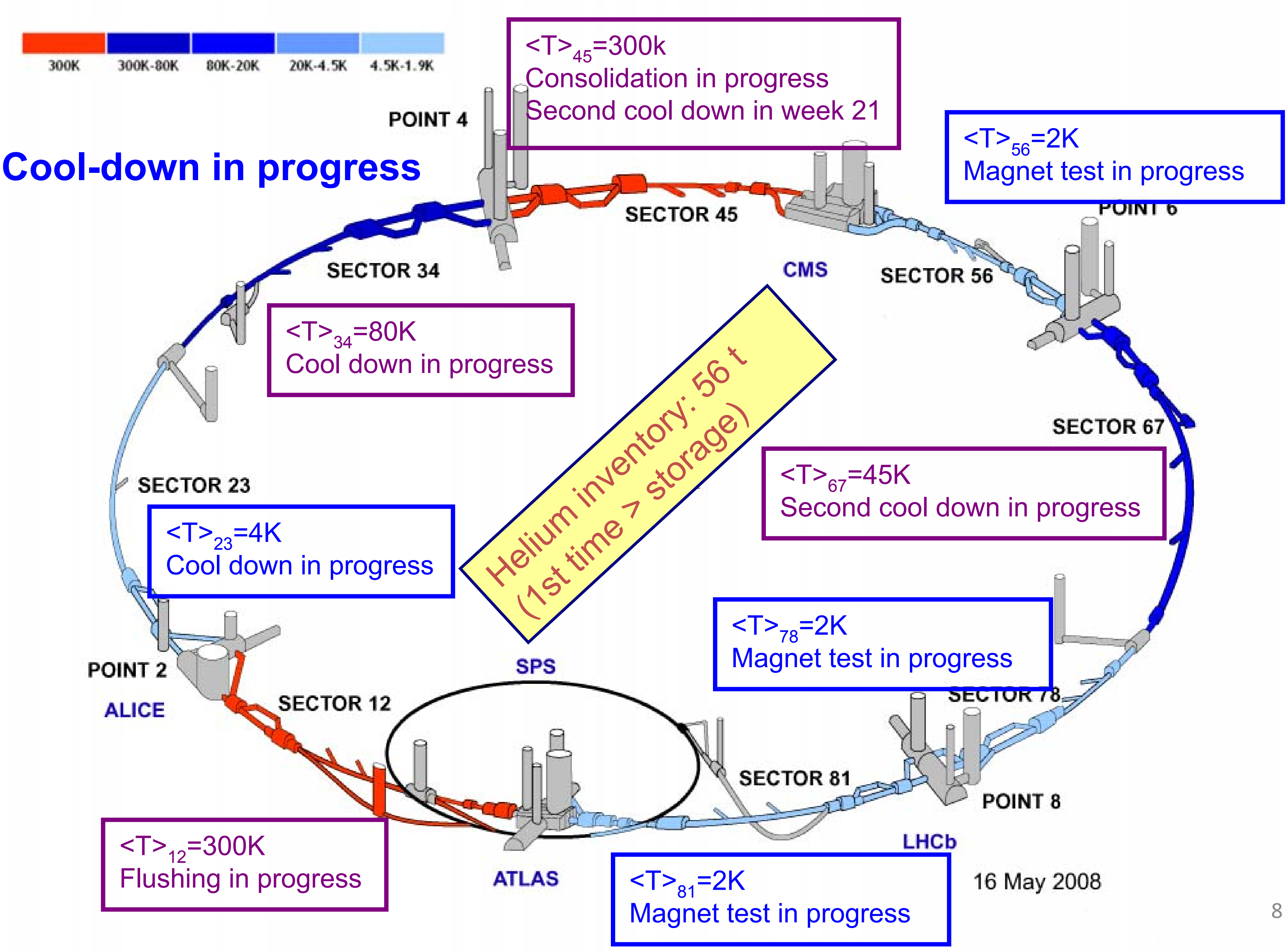
Closure of continuous cryostat - November 07

Cryogenics : HUGE SYSTEM

- ~120 tonnes of He
- 10,000 tonnes LN2
- Cold mass 31,000 tonnes

Status of the Large Hadron Collider

Cool-down in progress



$\langle T \rangle_{45}$=300k
Consolidation in progress
Second cool down in week 21

$\langle T \rangle_{56}$=2K
Magnet test in progress

$\langle T \rangle_{34}$=80K
Cool down in progress

$\langle T \rangle_{67}$=45K
Second cool down in progress

$\langle T \rangle_{23}$=4K
Cool down in progress

Helium inventory: 56 t
(1st time > storage)

$\langle T \rangle_{78}$=2K
Magnet test in progress

$\langle T \rangle_{12}$=300K
Flushing in progress

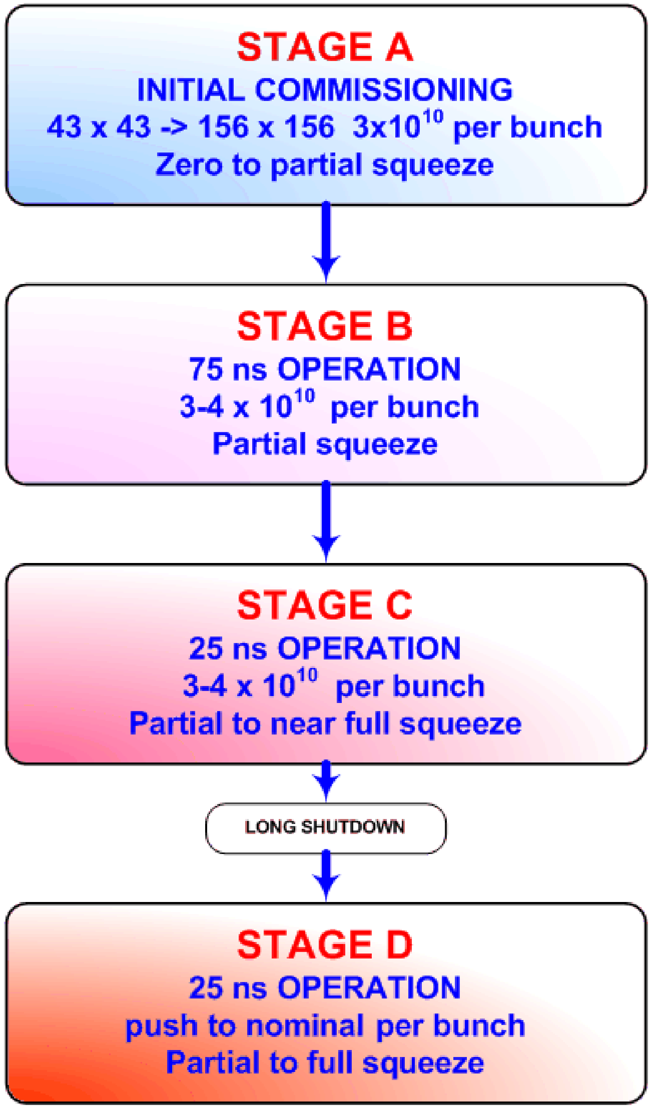
$\langle T \rangle_{81}$=2K
Magnet test in progress

16 May 2008

Cool-down in progress

sector	Average T [K]	status
12	300	flushing
23	4	Cool down
34	80	Cool down
45	300	Commissioning to 5 TeV (except for the triplet) Inner triplet connected Consolidation completed Second cool down starting
56	2	Fully commissioned to 5 TeV Dipoles and quadrupoles being trained to 7 TeV
67	45	Cool down
78	2	Partially tested in June 07 Inner triplet connected Powering test in progress
81	2	Powering test in progress

Commissioning of the LHC



STAGE A
INITIAL COMMISSIONING
43 x 43 -> 156 x 156 3×10^{10} per bunch
Zero to partial squeeze

STAGE B
75 ns OPERATION
3-4 x 10^{10} per bunch
Partial squeeze

STAGE C
25 ns OPERATION
3-4 x 10^{10} per bunch
Partial to near full squeeze

LONG SHUTDOWN

STAGE D
25 ns OPERATION
push to nominal per bunch
Partial to full squeeze

Safely establish colliding beams as quickly as possible

Stage A

- Initial optics:
  - β^*= 11 m in IR 1 & 5
  - β^*= 10 m in IR 2 & 8
- Crossing angles off
  - Low bunch intensity
  - 1, 12, 43, 156 bunches per beam
  - No parasitic encounters - no long range beam-beam
  - Larger aperture in IRs

Schedule 2008

- High parallelism for cool down and power tests until the End of July

- **1 July**: LHC **cooled down at 1.9 K** and the beam pipe in the experiments backed up
- **15 July**: the experimental **caverns closed,** tunnel patrolled, controlled access fully activated
- **1 August**: **first particles injected in LHC**, and the beam commissioning starts.

☺ **about 2 months to have first collisions at 10 TeV.**

- Energy of the 2008 run will be 10 TeV.
  - → safe setting to optimize up-time of the machine until the winter shut-down (starting likely around end of November)
- In the winter shut-down commissioning and train the magnets up to full current
  - → the 2009 run will start at the full 14 TeV energy

Pilot physics – the first months

- Interleaved physics and commissioning
- Push number of bunches, intensity, squeeze…
  - 156 x 156
  - 3 x 10^{10} protons per bunch
  - $\beta^* = 2$ m.
- Peak luminosity: 0.8×10^{31}
- Integrated luminosity: few pb^{-1}

Nov 08 ?

Pushing the bunch intensities with 156x156 with reasonable operational efficiency another month would see 30-40 pb^{-1}

2009

- Training to 7 TeV
- Circuits not commissioned in 2008
- Commission and exploit 75 ns.
- Move to 25 ns
- ions

- Initial luminosity 8 x 10^{32} $cm^{-2}s^{-1}$ (say)
- 2808 bunches, β^* = 2 m, 6 x 10^{10} protons per bunch
- Luminosity lifetime: 27 hours
- Fill length: 12 hours
- Turn around time: 5 hours
- 100 days of physics
- Operational efficiency 60%

$\int$ Ldt of the order 2-3 fb^{-1}

Machine Protection is critical…

2808 bunches, 1.15 10^{11} protons per bunch

British aircraft carrier at 12 knots

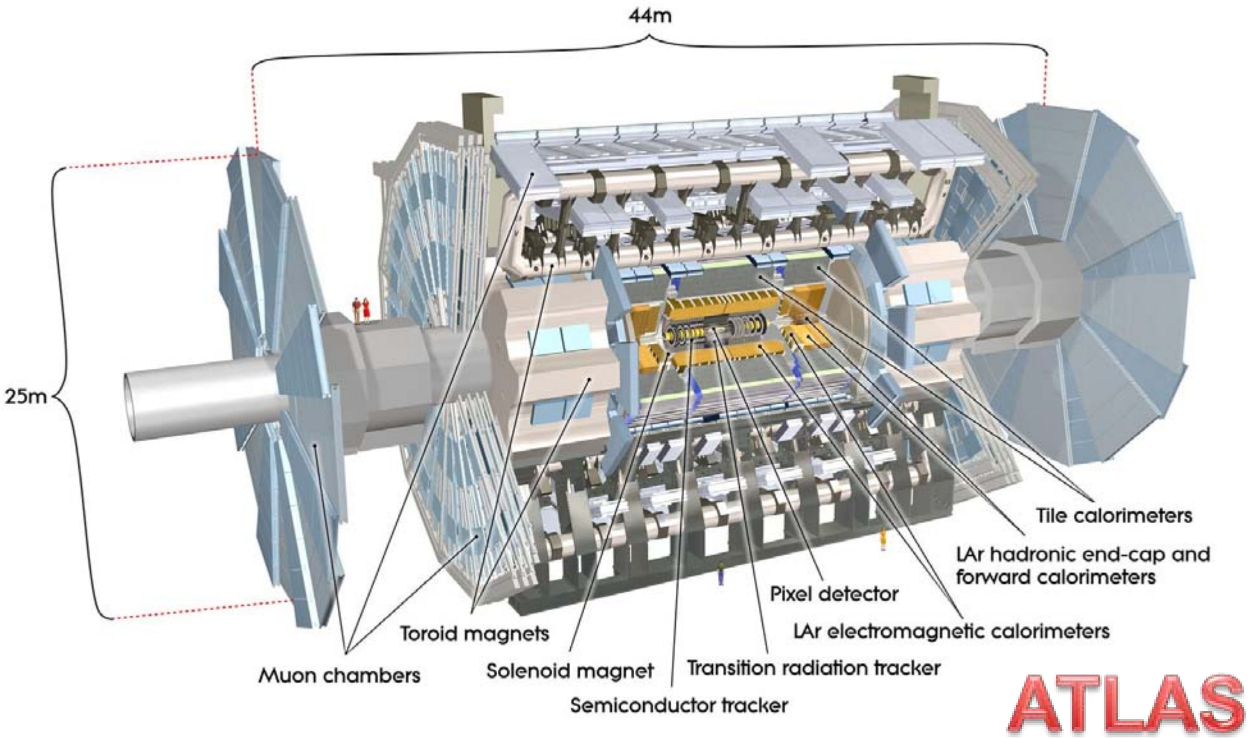
Through a very cold, very dark, very small hole...

Machine Protection is critical…

R. Schmidt and J. Uythoven, June 2nd , 2009, LHC point 6:
Discussion on how the Beam Dump System reliability could be improved

The ATLAS and CMS detectors

The ATLAS Detector



ATLAS superimposed to the 5 floors of building 40

ATLAS ~100% installed!

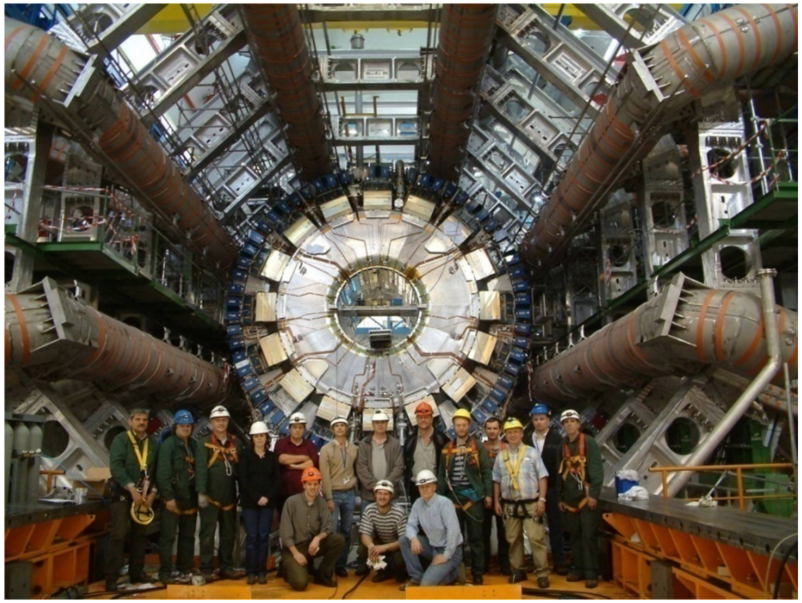
Sub-detector	N. of channels
Pixels	80×10^6
Silicon strip detector (SCT)	6×10^6
Transition Radiation Tracker (TRT)	3.5×10^5
Electromagnetic calorimeter	1.7×10^5
Fe/scintillator (Tilecal) calorimeter	9800
Hadronic end-cap LAr calorimeter	5600
Forward LAr calorimeter	3500
Barrel Muon Spectrometer	7×10^5
End-cap Muon Spectrometer (TGC)	3.2×10^5
Forward detectors	1.2×10^4
total	$\sim 87.6 \times 10^6$

Parameter	ATLAS
Total weight (tons)	7,000
Overall diameter (m)	22
Overall length (m)	46
Magnetic field for tracking (T)	2
Solid angle for lepton ID or tracking $(\Delta\phi \times \Delta\eta)$	$2\pi \times 5.0$
Solid angle for energy measurements $(\Delta\phi \times \Delta\eta)$	$2\pi \times 9.6$

Detector parts staged:

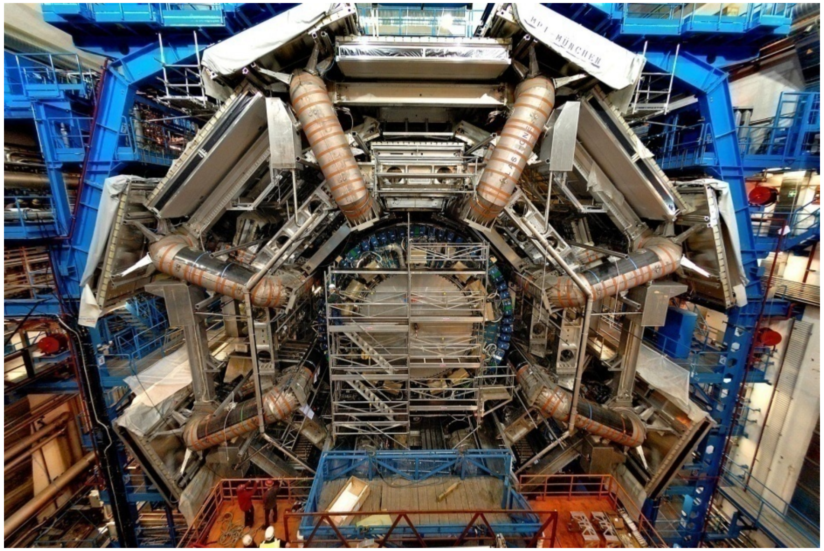
- **TRT: endcap wheel C**
- **Muon Spectrometer: BEE chambers (next year) and half CSC chambers**

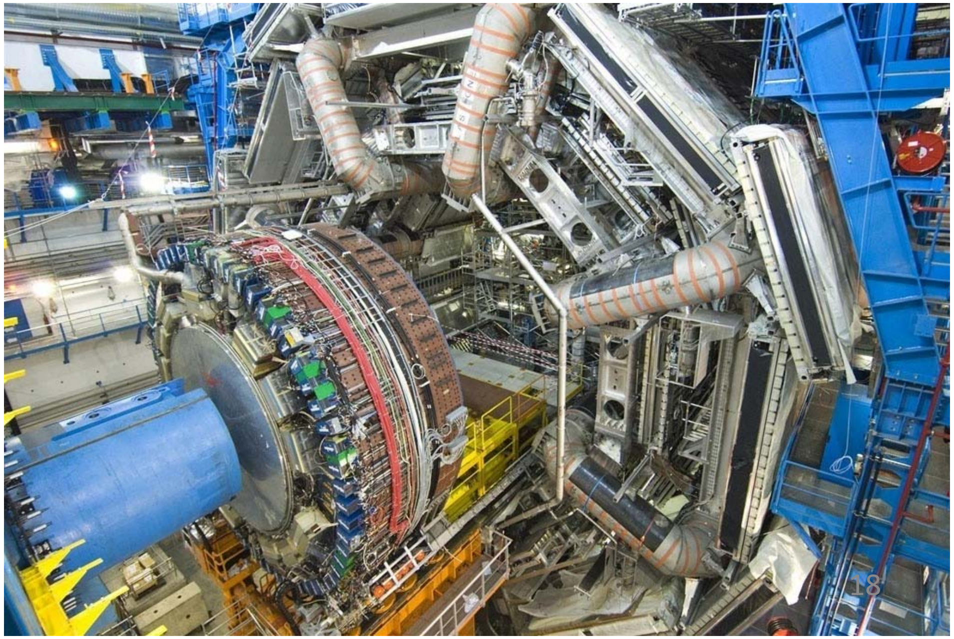
Calorimeter



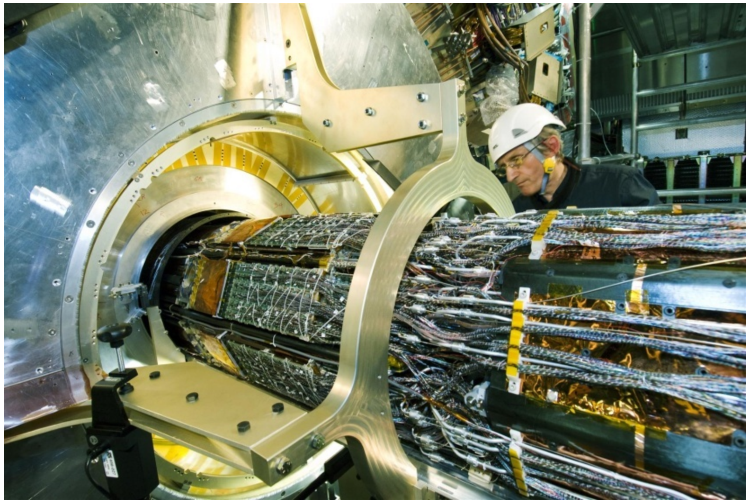
Hadronic barrel (tile calorimeter) was the first detector to be integrated (2006).

Three (barrel + 2 endcaps)
cryostats installed and filled with LAr.
Detectors operated for long time last year.

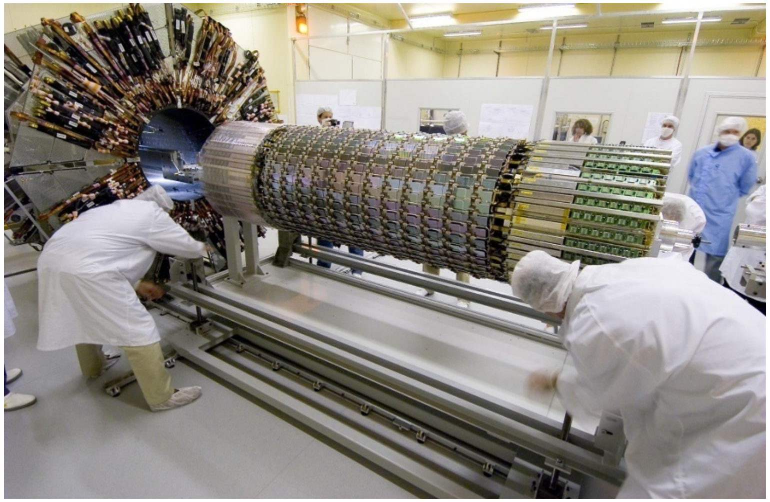


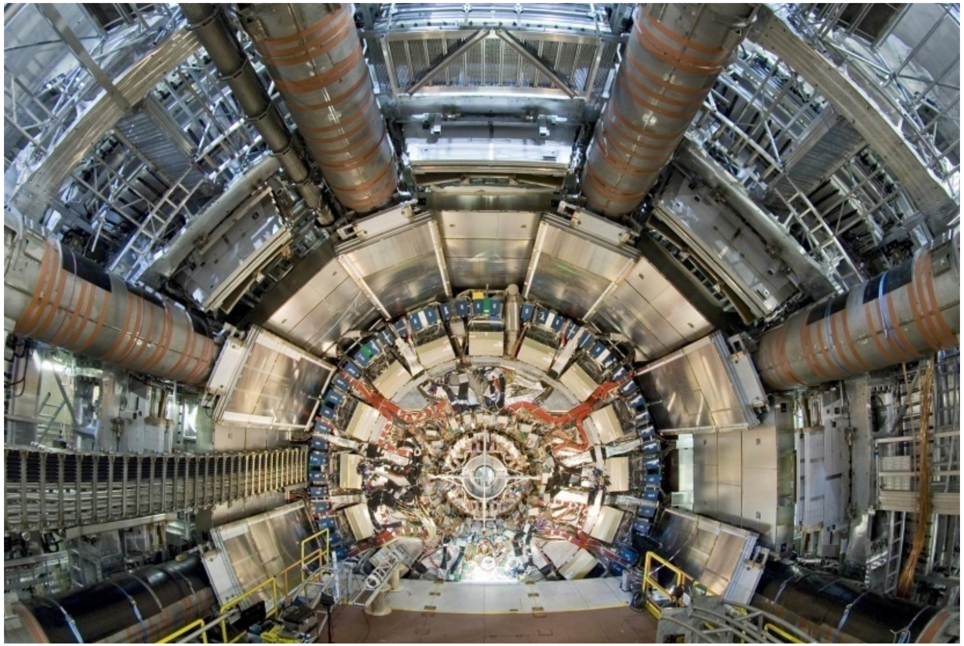


Inner Detector

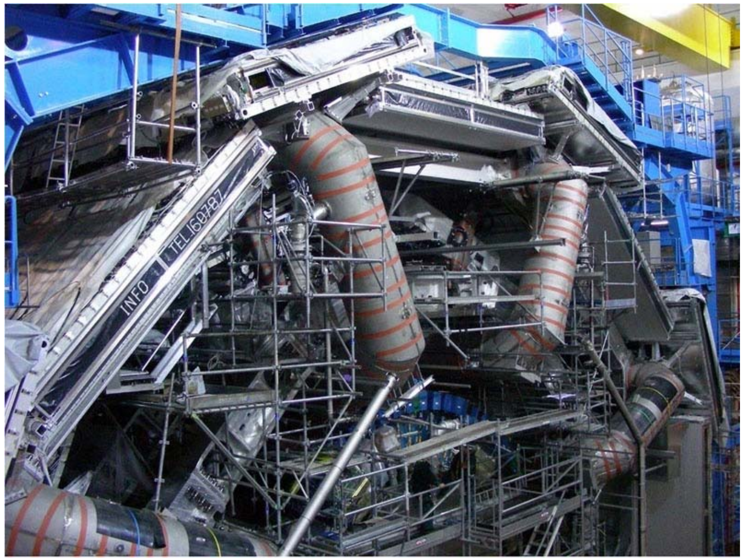


All **ID subdetectors** (Pixels, SemiConductor Tracker, Transition Radiation Tracker) have been installed.

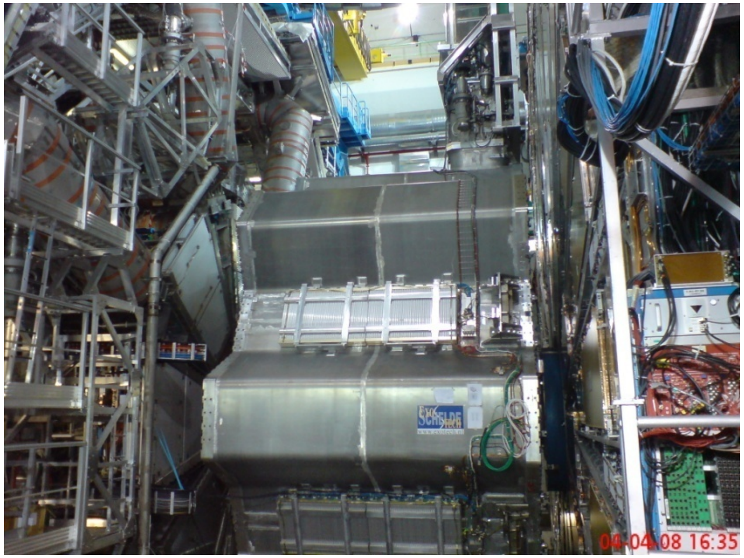


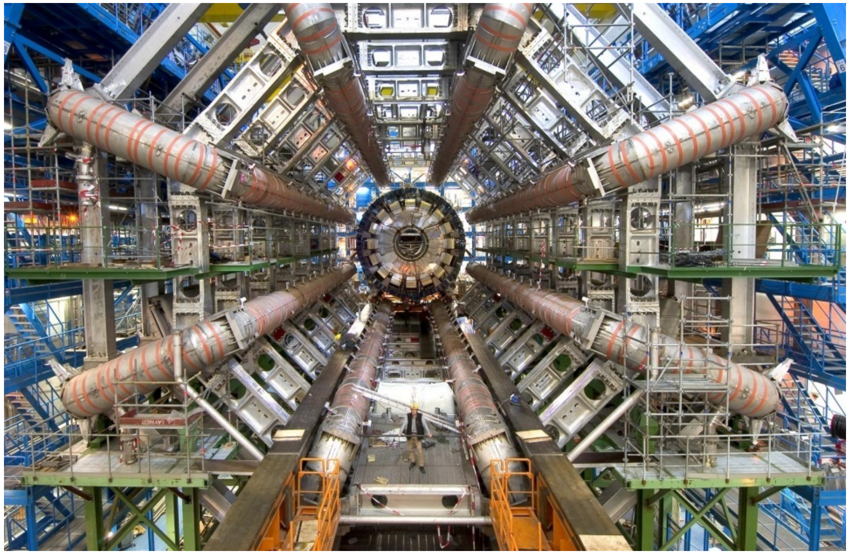


Muon Spectrometer

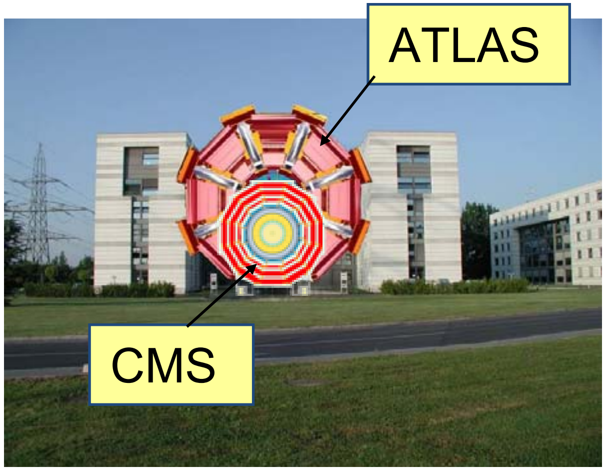


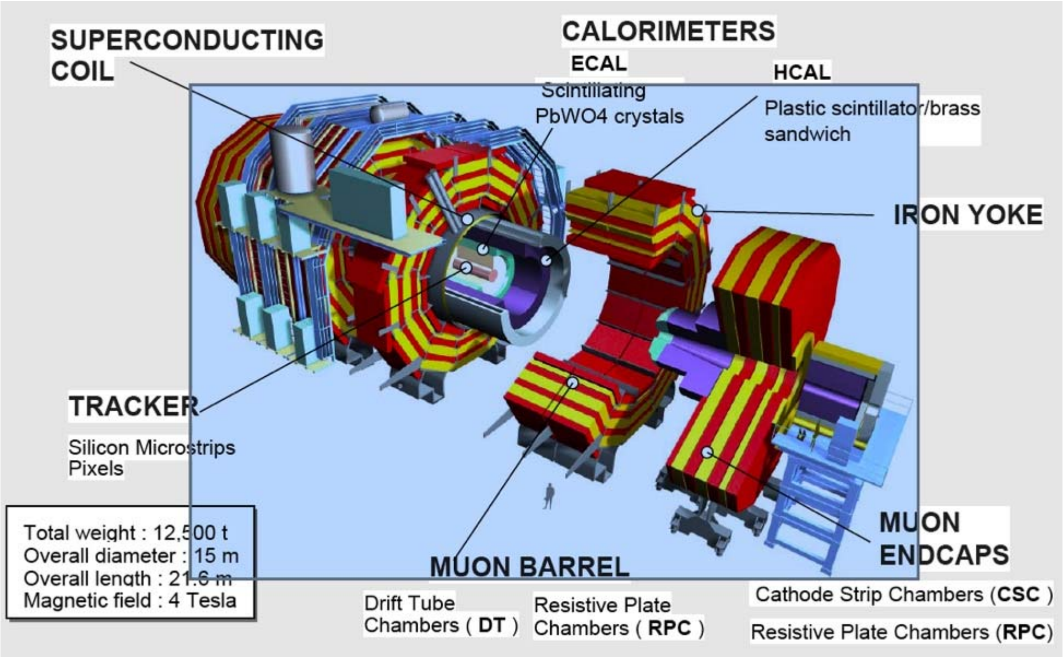
- The **Muon Chambers** are all installed; the system as-built it corresponds to the nominal design: just a few muon stations are staged.
- The commissioning is still on going.





The CMS Detector

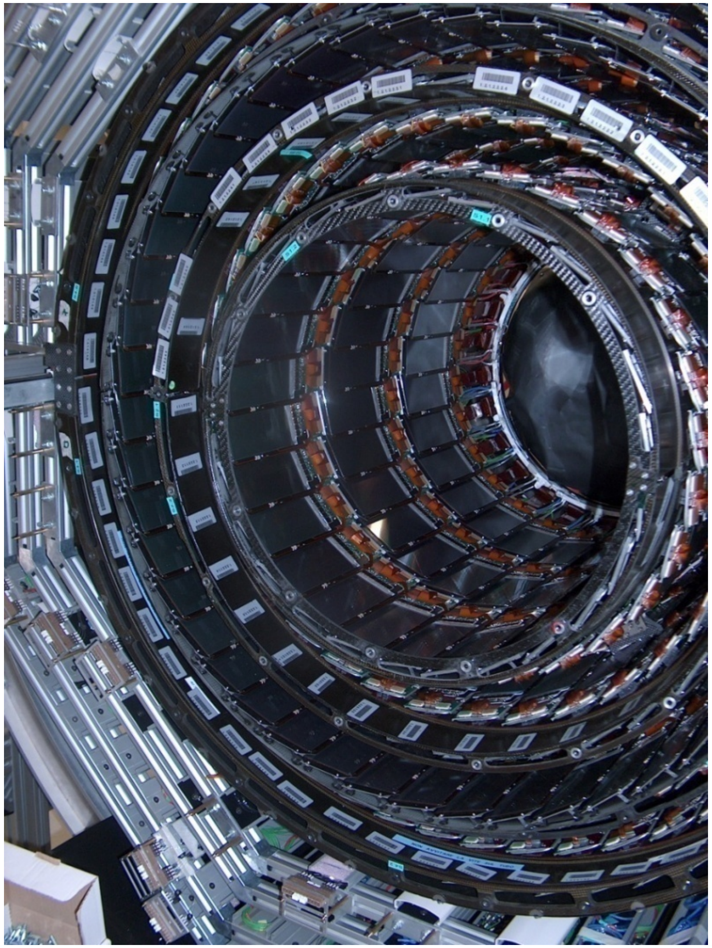




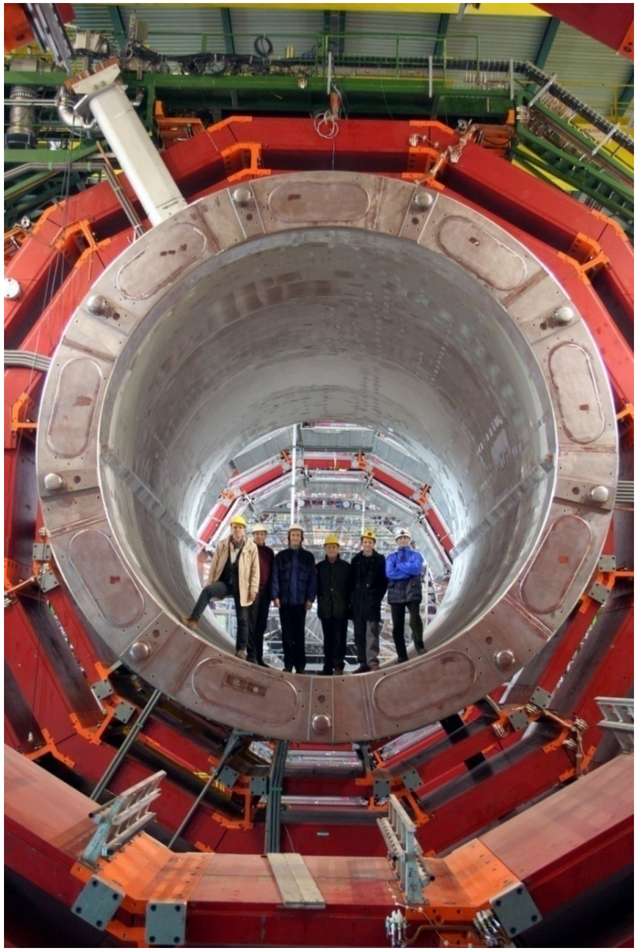
1. Robust and Redundant Muon system
2. Best e/γ calorimeter consistent with 1.
3. Efficient Tracker consistent with 1. and 2.
4. Hermetic calorimeter
5. Affordable

- **Tracker installed in Dec. 07 and fully cabled**
- **Complete bake-out of beam-pipe by mid-June**
- **Install Pixels detector and one ECAL endcap after bakeout**
- **Install second ECAL endcap if LHC startup schedule allows**
- **Detector ready to close mid July**
- **Magnet is already cold and ready to be powered after closure**

CMS

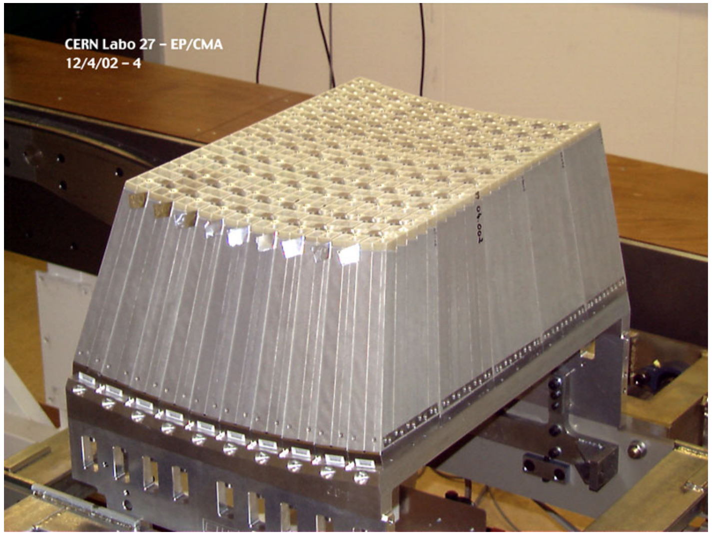


The Inner Tracker



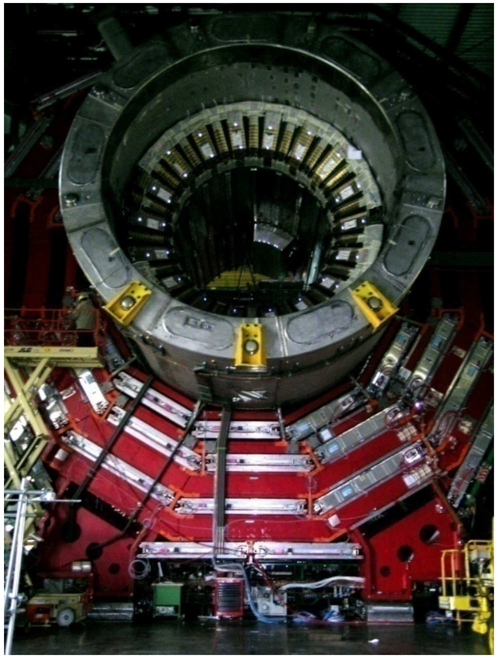
The 4T Solenoid

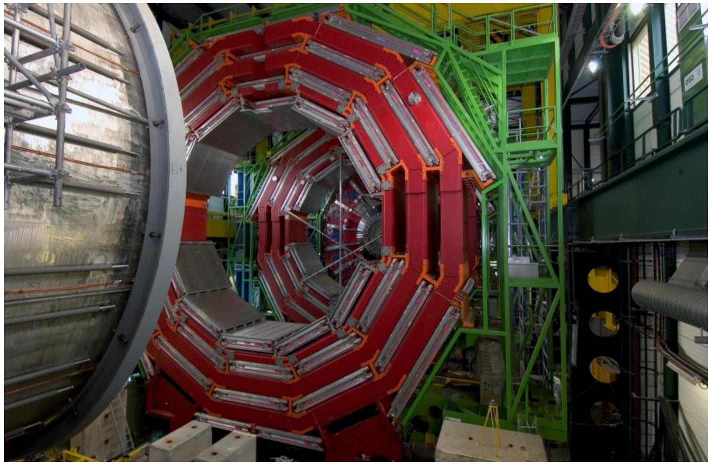
CMS



ECAL Module

Barrel Hadronic Calorimeter



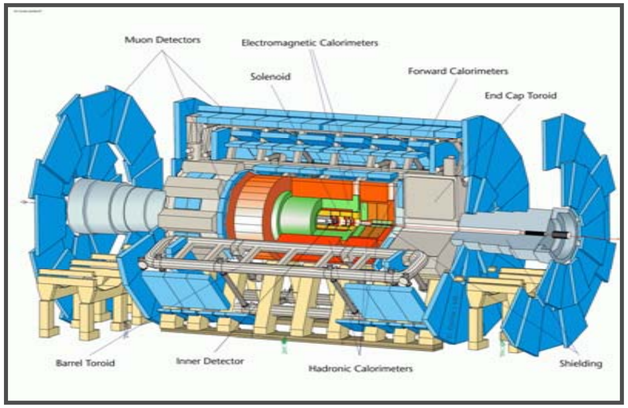


Barrel Muon System

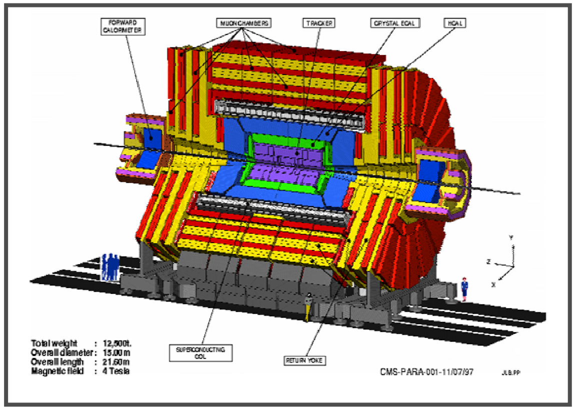
Endcap Muon System

CMS

Closing CMS for the first time (July 2006)



ATLAS
and
CMS



	A Toroidal LHC ApparatuS	Compact Muon Solenoid
MAGNET	3 air-core toroids + solenoid in inner cavity Calorimeters in field-free region	Only one Solenoid Calorimeters inside field
TRACKER	Si pixels + strips + TRT for particle identification Solenoid B = 2T $\sigma/p_T \sim 5 \times 10^{-4} p_T \oplus 0.01$	Si pixels + strips Solenoid B = 4T $\sigma/p_T \sim 1.5 \times 10^{-4} p_T \oplus 0.005$
EM CALO	Pb-liquid Argon Longitudinal segmentation $\sigma/E \sim 10\%/\sqrt{E} \oplus 0.007$	PbWO4 crystals $\sigma/E \sim 2\text{-}5\%/\sqrt{E} \oplus 0.005$
HADRONIC CALO	Fe-scint. + Cu-liquid Argon (10λ) $\sigma/E \sim 50\%/\sqrt{E} \oplus 0.03$	Cu-scint. (>5.8λ+catcher) $\sigma/E \sim 100\%/\sqrt{E} \oplus 0.05$
MUON	Optimal performance also standalone $\sigma/p_T \sim 2\% @ 50\text{GeV} \div 10\% @ 1\text{TeV}$ (ID+MS)	Combining with tracker $\sigma/p_T \sim 1\% @ 50\text{GeV} \div 5\% @ 1\text{TeV}$
TRIGGER	LVL1 + LVL2 (Region of Interest) + EF	LVL1 + HLT (LVL2 + LVL3)

What’s new on Higgs Studies @ LHC?

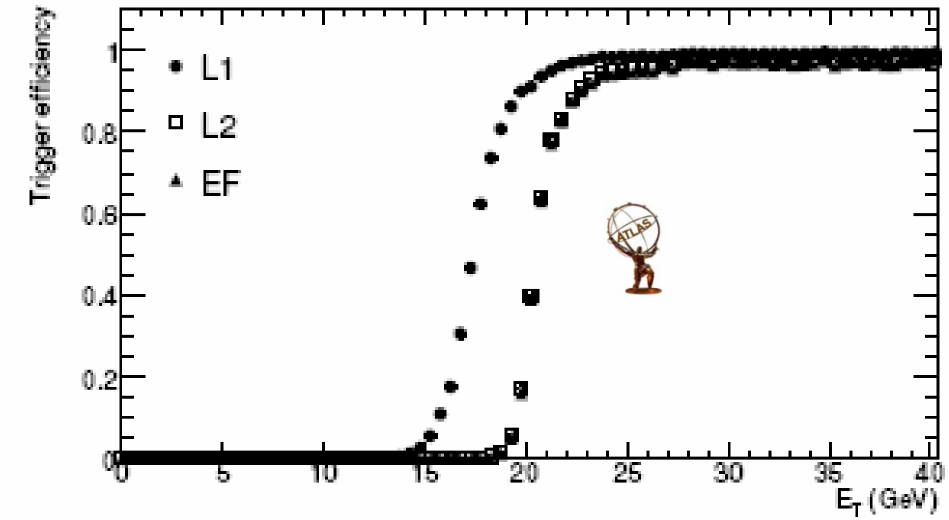
- Many studies have meanwhile been performed using **detailed GEANT simulations of the ATLAS and CMS detectors**
  - Physics Performance Technical Design Report from the CMS collaboration
  - ATLAS CSC (Computing System Challenge) Notes, to be released now…
- **New (N)NLO Monte Carlos** (also for backgrounds)
  - 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
- **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 accurate and better event reconstruction based on test beam results**

H →γγ

- Search for two isolated photons
  - **Trigger** : single or double photon selection
    - ATLAS: 2γ17i , γ60 ; CMS: 2γ12i)
  - **Offline**: $p_T(1)>40$ GeV, $p_T(2)>35$ GeV (CMS)
    - Produced by the same vertex

- Signal: 0.1 pb , m_H=115 GeV
  - Gluon-gluon fusion
  - Vector Boson Fusion
  - Associated production (ttH, WH, ZH)

ATLAS Trigger efficiency for single photons (normalized to offline loose selection)



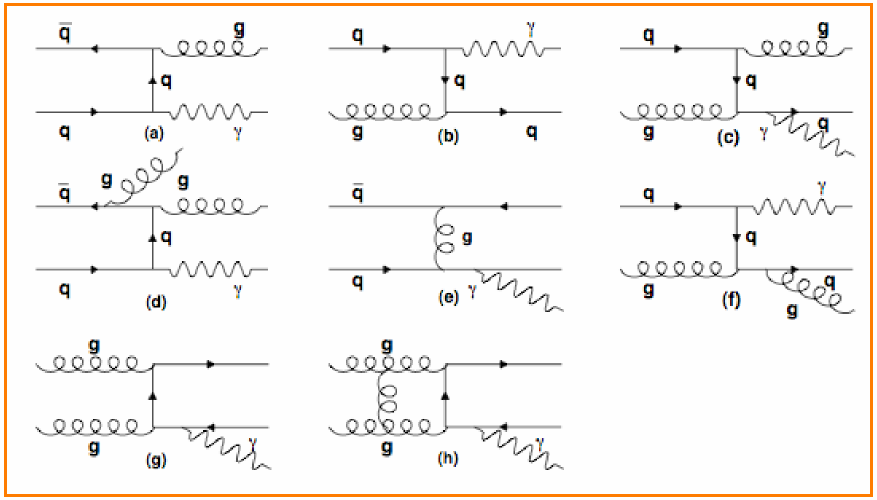
2γ17i rates at
$L=10^{33}$ cm^{-2}s^{-1}:
LVL1: 140 Hz
LVL2: 5 Hz
EF: 2 Hz

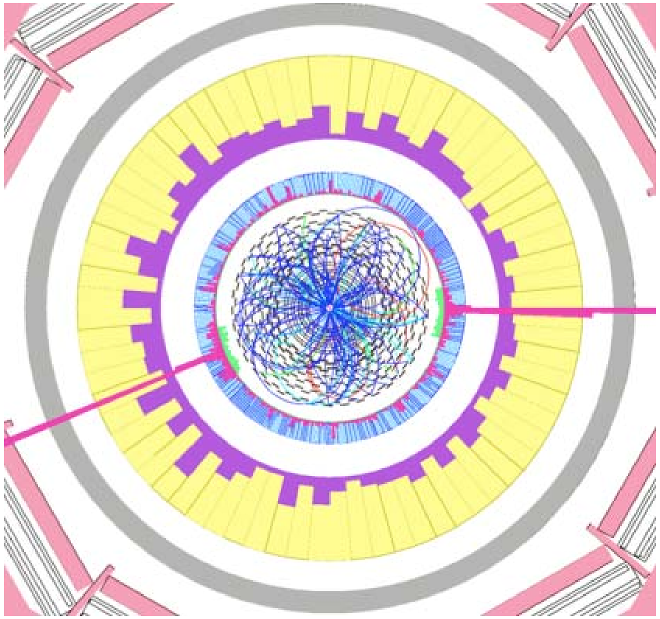
Efficiency for a 120 GeV Higgs: ~94%

H →γγ

- Background, computed at the NLO: ±20÷30% (ATLAS uses full NLO event simulation)
  - **Irreducible**: pp→γγ+X, born + box, σ=80 + 80 pb
  - **Reducible**: pp→g+jets (σ~10^4 pb);
    pp→ γ+jets (σ~10^7 pb);
- **It will be measured from data sidebands**

Example: NLO γ-jet processes



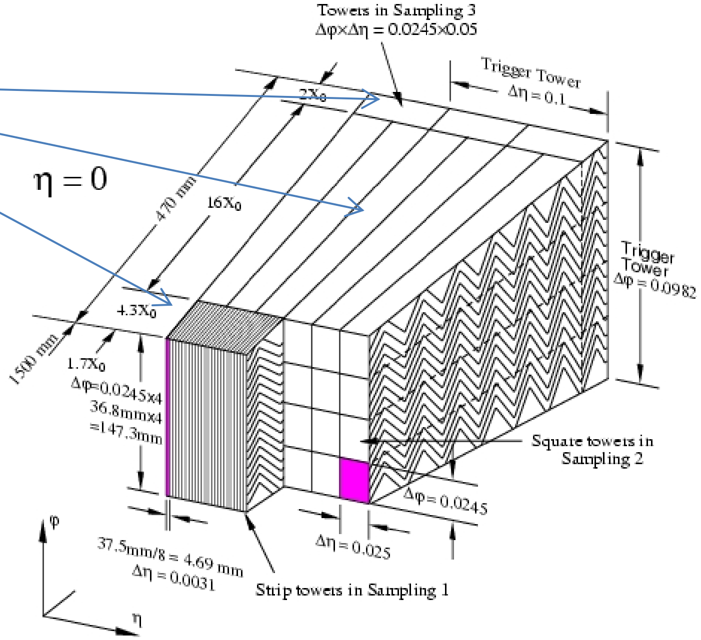


Experimental requirements:

- Excellent electromagnetic energy resolution;
- high photon efficiency and strong p^0/jet rejection
- Good γγ-vertex reconstruction

H $\rightarrow\gamma\gamma$: jet rejection

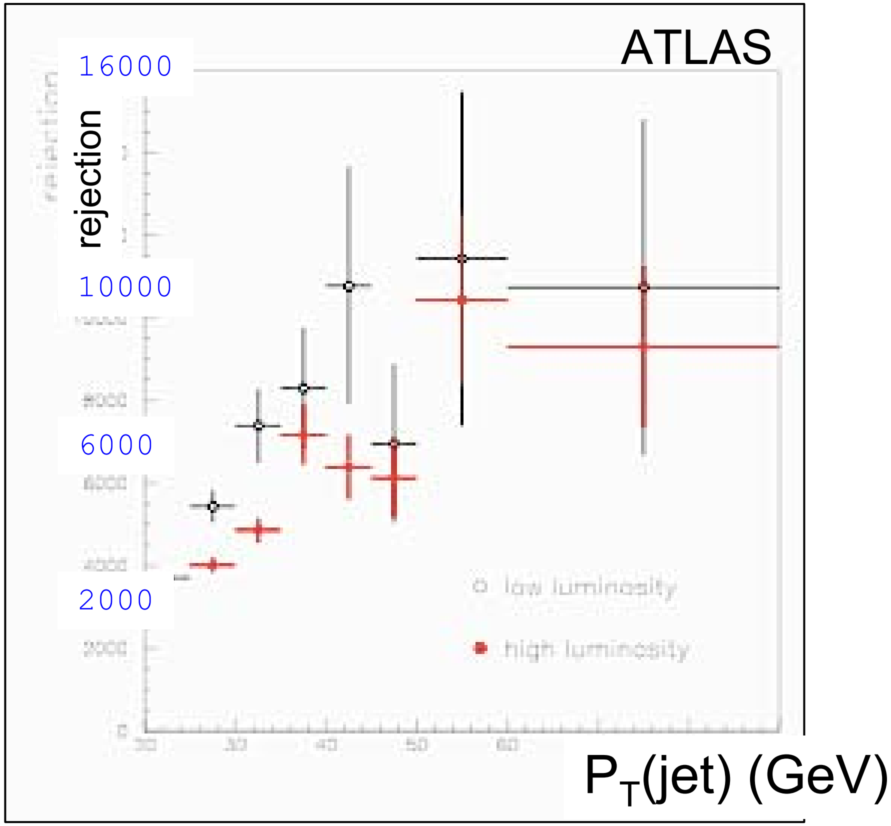
- ATLAS:
  - use longitudinal segmentation of the calorimeter
    - Reject hadron showers
  - use very fine segmentation of the firs layer of the e.m. calorimeter (eta-strips)
    - Reject π^0s
  - Measure isolation of the e.m. cluster
    - Reject hadron showers
  - Measure isolation around the photn analyzing tracks reconstructed in the ID



E.M. Calo module of ATLAS

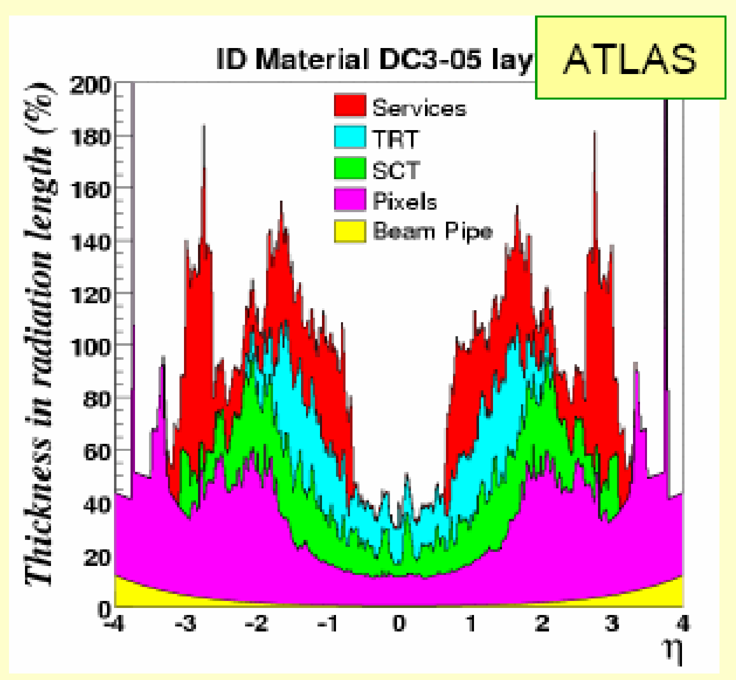
- CMS: very similar to ATLAS (except no e.m. longitudinal segmentation, no preshower)

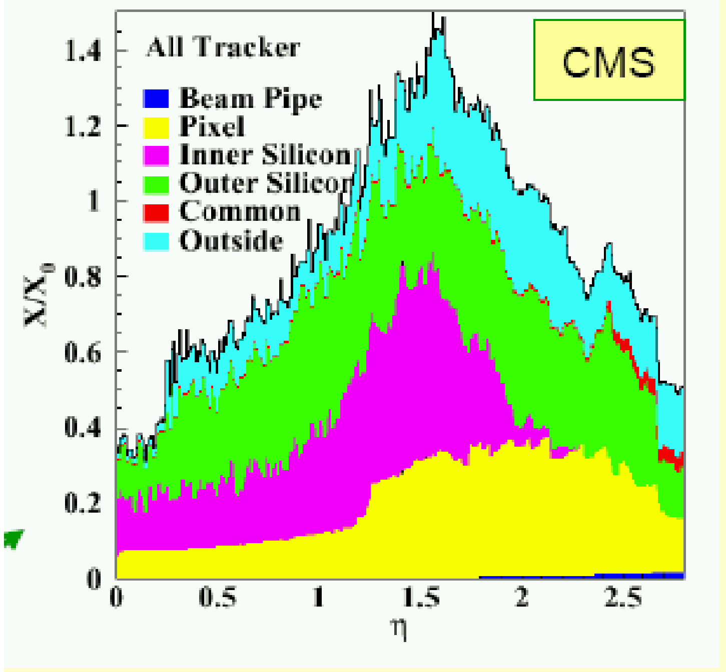
H →$\gamma\gamma$: jet rejection



- reducible background ~30% of irreducible
- γ-jet (mainly q) is now the 85% of the reducible background and dominates over jet-jet (mainly g)
- Average photon efficiency (non-converted and converted): ~ 80%

H →γγ : photon conversions





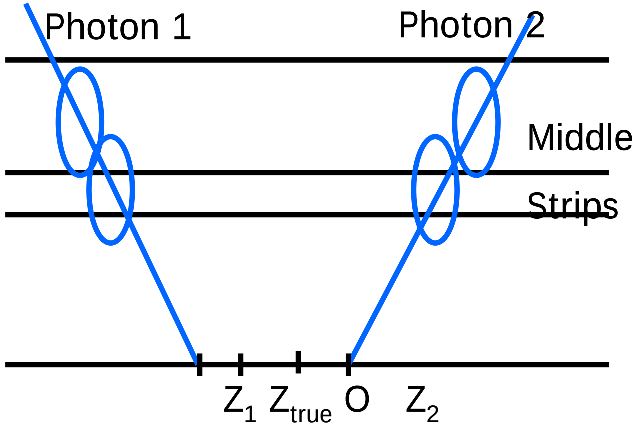
Converted photons are an important issue: ~50% of the events with at least one converted photon:

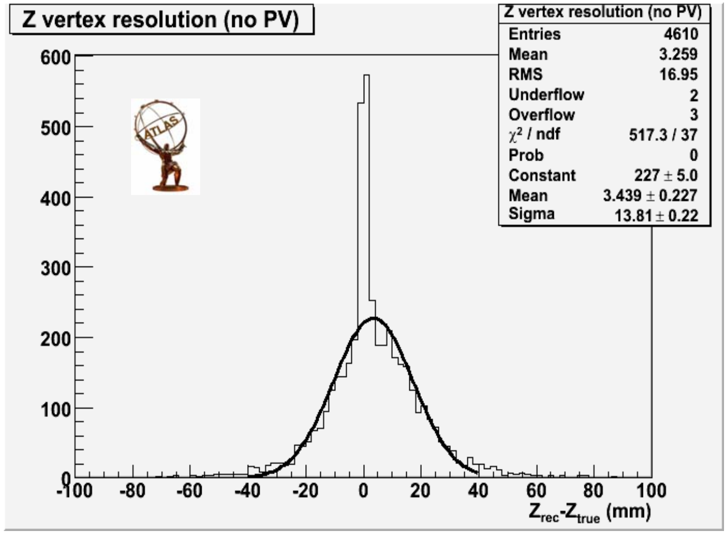
- energy reconstruction is degraded: ad hoc recalibration required.
- conversion vertex can be used to compute the direction

Some conversions are detected also in events where one track is reconstructed.

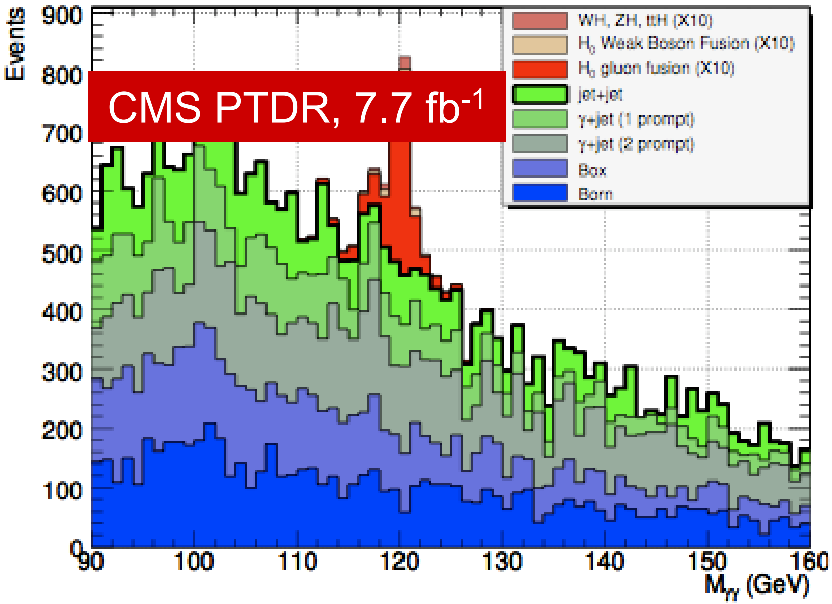
H →$\gamma\gamma$: primary vertex reconstruction

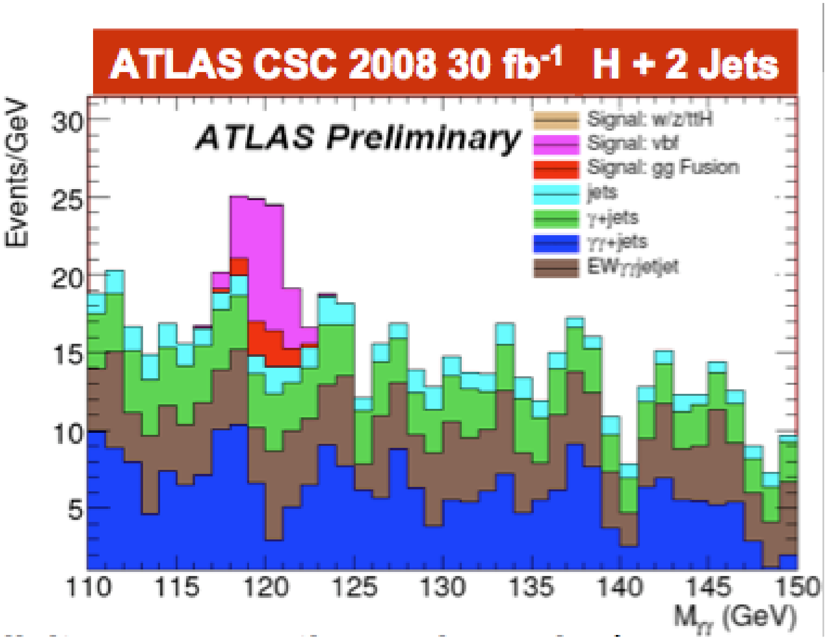
- The primary vertex identification is crucial to the precise $\gamma\gamma$ invariant mass measurement.
  - ATLAS:
    - Use longitudinal segmentation and preshower strips to measure the γ flight direction. Vertex position acccuracy: 17 (using conversions) to 19 mm.
    - Use ID (low luminosity): resolution: 40 µm.
  - CMS:
    - Use ID (low luminosiity): resolution: 40 µm.
    - Use only high-pt tracks to identify the primary vertex: at low luminosity it provides the correct vertex in 81% of the cases





H →γγ : results

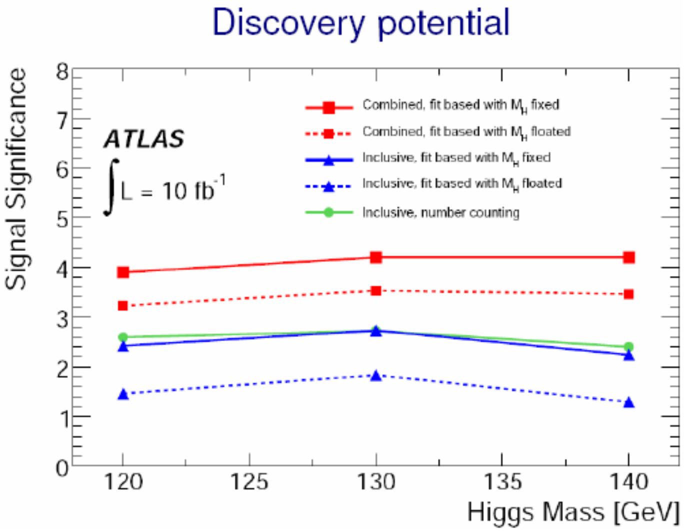




- Optimized neural network analysis and cut base analysis (CMS)
  - Allows for 5σ discovery with 20-30 fb^{-1} for M_H < 140 GeV
    - Dominant systematics from signal (15% theory, 5% luminosity, 1% trigger, 1% ΔX_o tracker)
      - Degrades exclusion limits, but does not affect discovery potential
- Recent results (ATLAS)
  - Events are split into categories (jet multiplicity, energy ratios, η region)
  - Combine various channels to increase significance: inclusive, 1 and 2-jet analyses
  - Use of fit and likelihood ratio for discovery + systematics
  - Mass resolution: 1.36 GeV. Reconstruction efficiency: :~34%

H →$\gamma\gamma$: discovery potential

ATLAS:

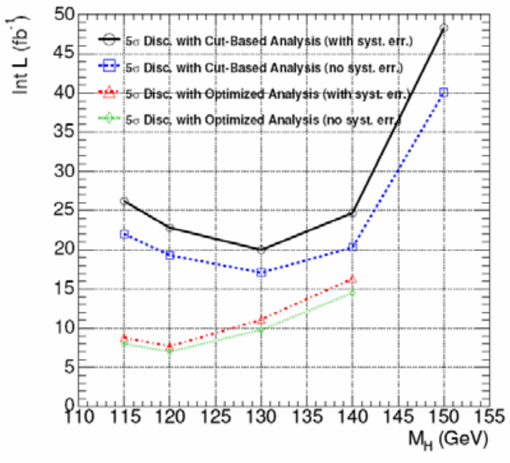


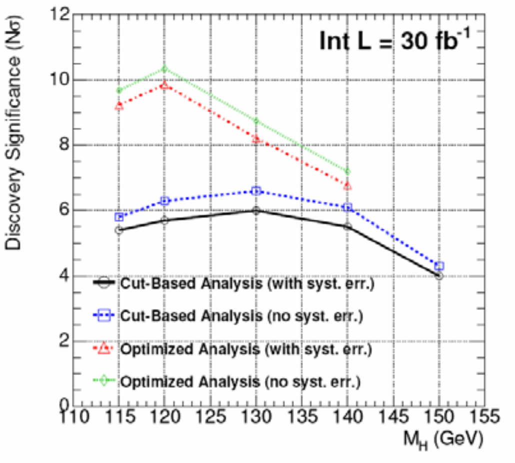
Builds a likelihood including also

1.$\gamma\gamma$ -P_T (background has softer spectrum and less pronounced rise at low P_T).

2.cosθ*, the photon decay angle in the H rest frame with respect to the H flight direction in the lab rest frame (the background distribution is somewhat enhanced for collinear photons).

CMS:

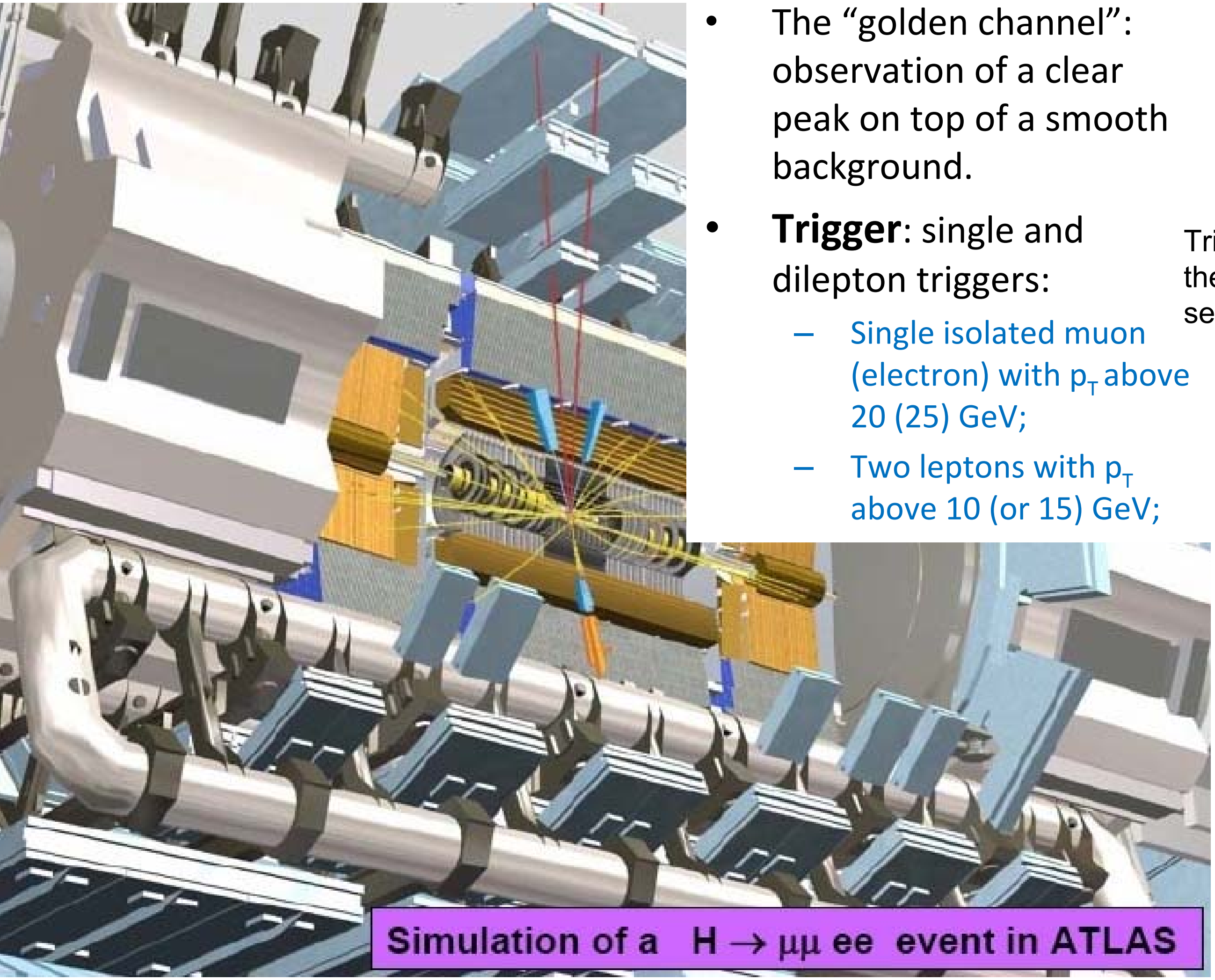


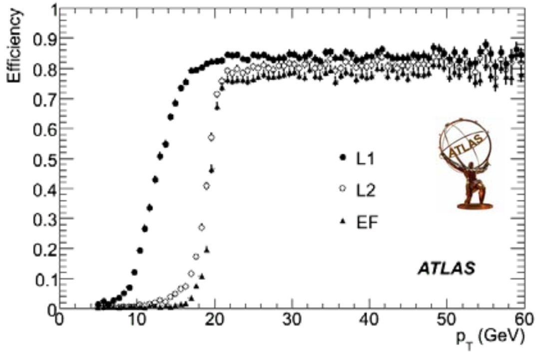


Uses 6 variables: isolation of each photon, $E_{Ti}/M_{\gamma\gamma}$, $|\eta_1-\eta_2|$, $P_{L\gamma\gamma}$ (E_{Ti} and η_i are the transverse energy and pseudorapidity of i-th γ)

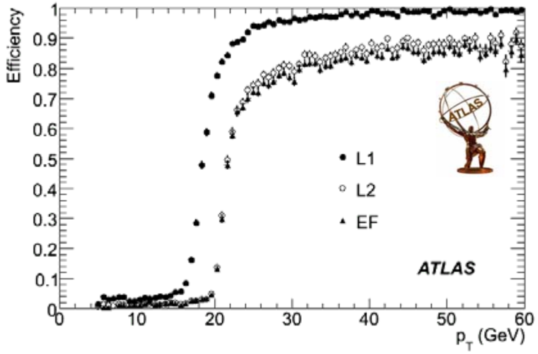
H →ZZ→4ℓ

- The "golden channel": observation of a clear peak on top of a smooth background.
- **Trigger**: single and dilepton triggers:
  - Single isolated muon (electron) with p_T above 20 (25) GeV;
  - Two leptons with p_T above 10 (or 15) GeV;


Simulation of a H → μμ ee event in ATLAS



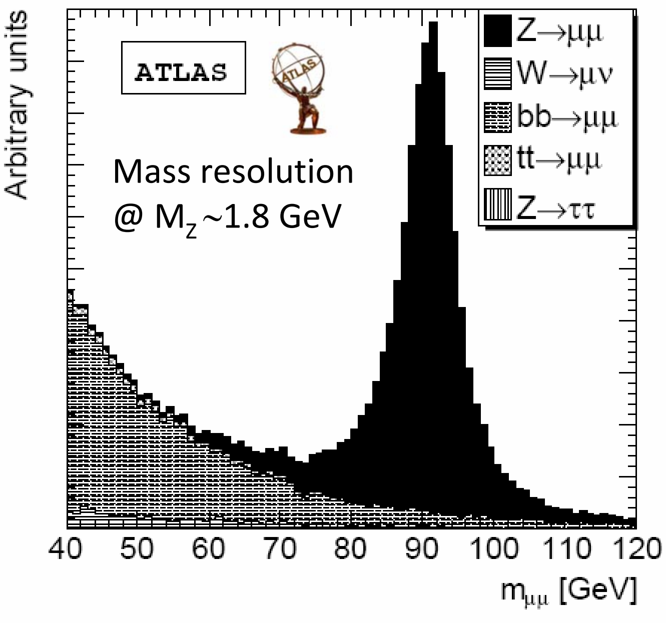
Trigger efficiency of muons as a function of the true transverse momentum. The selection threshold is p_T^{thres}.=20 GeV/c.



Trigger efficiency of electrons as a function of the true transverse momentum. The selection threshold is p_T^{thres}.=22 GeV/c, and the isolation was also required.

H →ZZ→4ℓ

- Backgrounds (l=e,μ, $|\eta|<2.7$, pT>5 GeV):
  - qq,gg → $ZZ^{(*)}$→4l (l=e,m,t) 56 fb (NLO);
  - qq → Zbb→4l 810 fb (NLO);
    - qq → Zbb→3l 1.3 pb (NLO);
  - qq,gg→tt 833 pb (NLO);
  - qq,gg →WZ→3l 386 fb (NLO);
  - Z→2l+X, 4030 pb (NNLO)
- Reconstruction:
  - Relatively low p_T isolated muons and electrons associated to the same primary vertex;
  - Reconstruct at least one Z→ℓℓ.
  - Reconstruct the 4l invariant mass → safe lepton identification and very good energy measurement



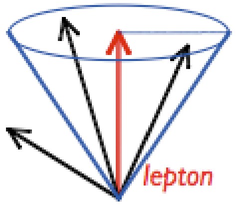
Mass resolution @ M_Z~1.8 GeV

Z→ee shows a worst resolution because the electron bremsstrahlung.

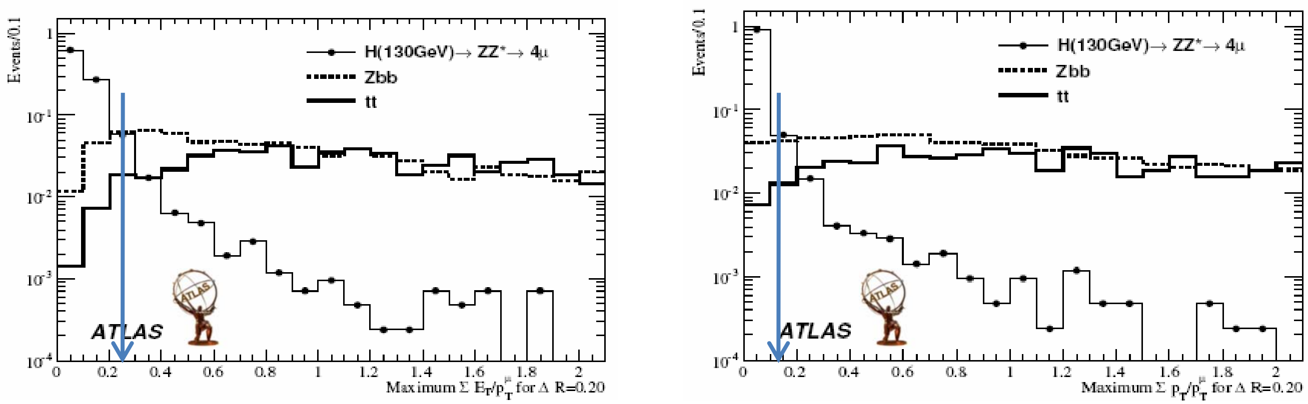
CMS mass resolution:
Z→ee: 1.8%, Z→$\mu\mu$: 1.1%

H →ZZ→4ℓ

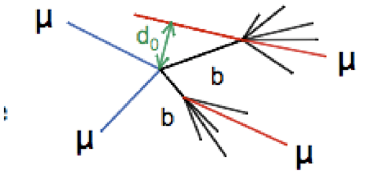
$$\Delta R = \sqrt{\Delta\eta^2 + \Delta\phi^2}$$



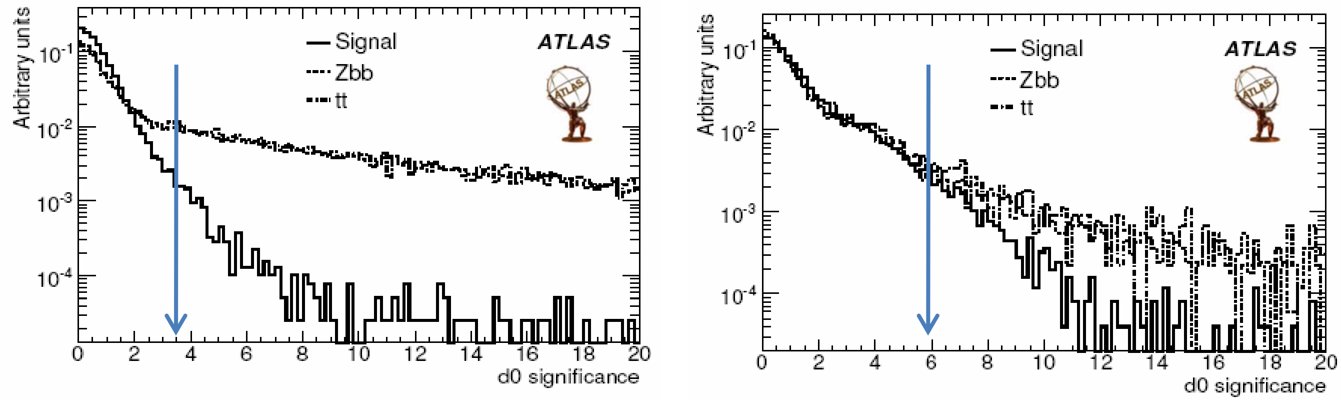
Reducible backgrounds have activity around leptons from b-decay



Normalized calorimetric (left) and track (right) isolation (Δ*R=0.2) for the signal* (*m_H = 130) and the Zbb* and tt backgrounds for the 4μ channel.



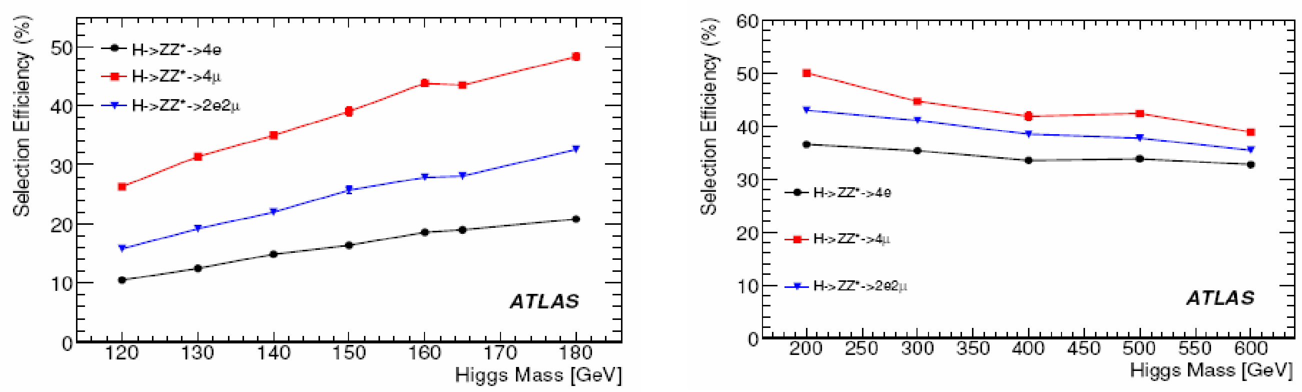
Lepton from b-quark decay do not point towards primary vertex



Transverse impact parameter significance for the muons (left) and electrons (right) in signal and reducible background events.

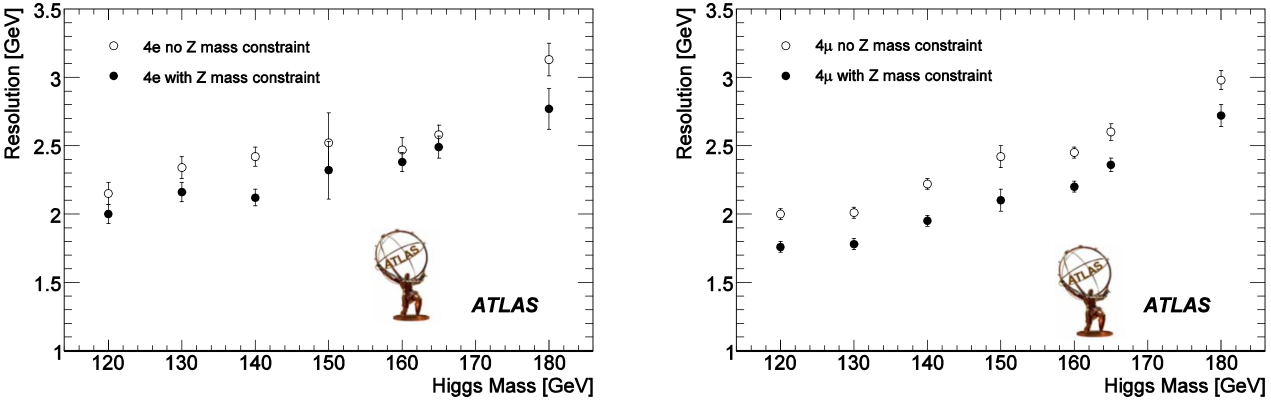
$H \rightarrow ZZ \rightarrow 4\ell$

ATLAS Higgs reconstruction eff.



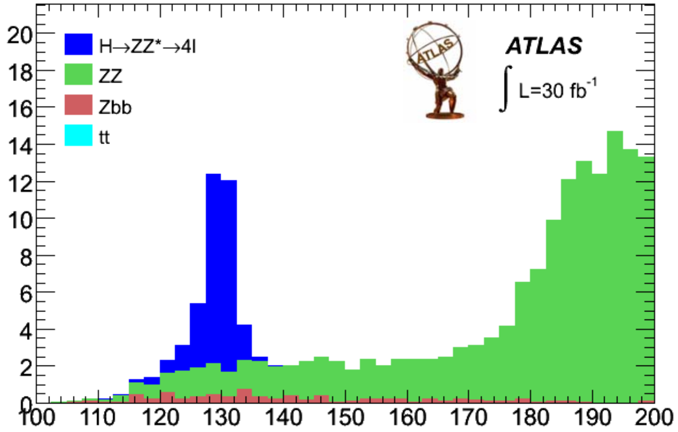
Selection effciency for as a function of the Higgs mass, for each of the three decay channels, for the case of only one on-shell Z (left) and both (right)

ATLAS Higgs mass resolution

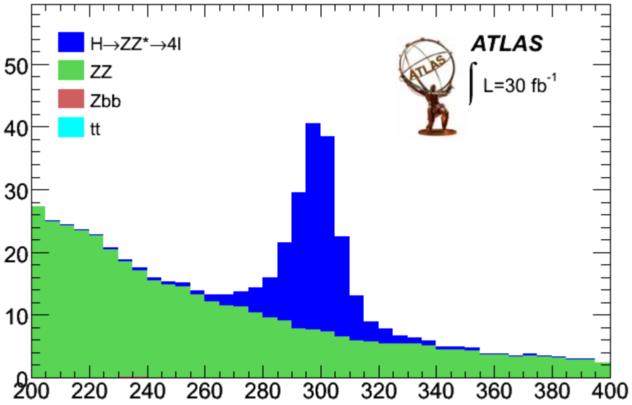


Higgs→4*e mass (left) and* Higgs→4*e mass (lright) resolution as a function* of the Higgs mass. Open circles denote the resolution obtained when no Z mass constraint is applied, while full circles show the resolution in the case of the Z mass constraint.

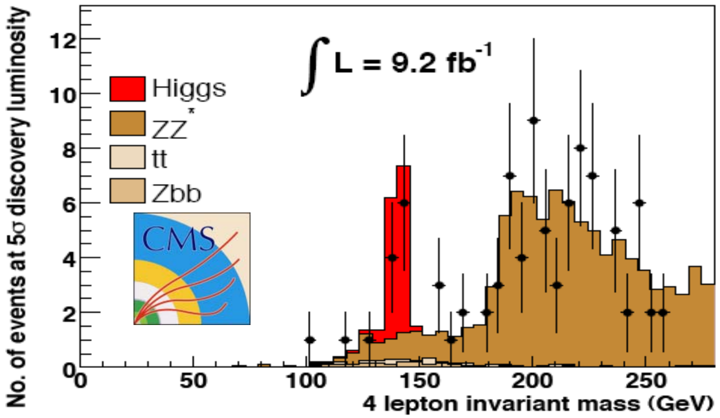
H →ZZ→4ℓ

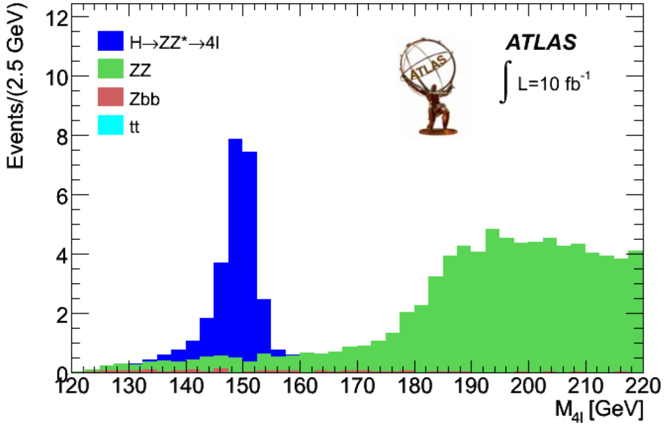


Reconstructed 4-lepton mass for signal and background processes, in the case of a 130 GeV Higgs,, normalized to a luminosity of 30 fb^{-1}.



Reconstructed 4-lepton mass for signal and background processes, in the case of a 300 GeV Higgs,, normalized to a luminosity of 30 fb^{-1}.

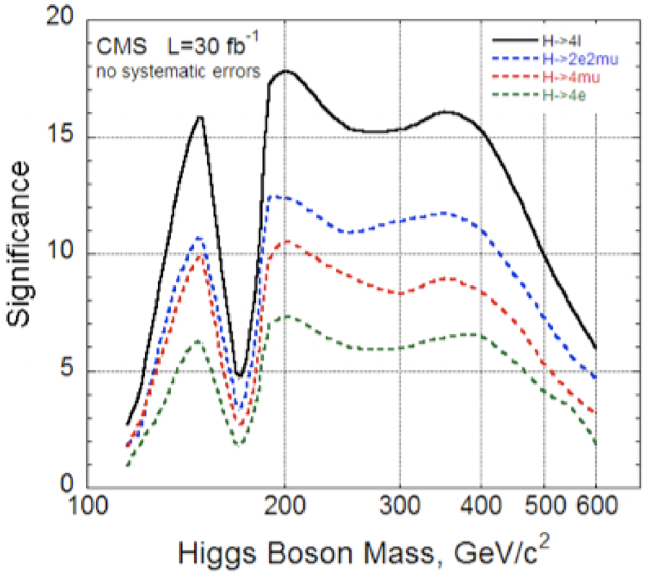


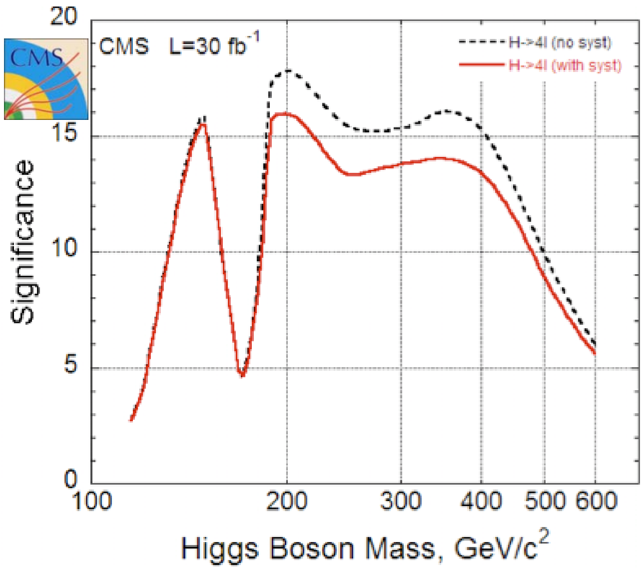


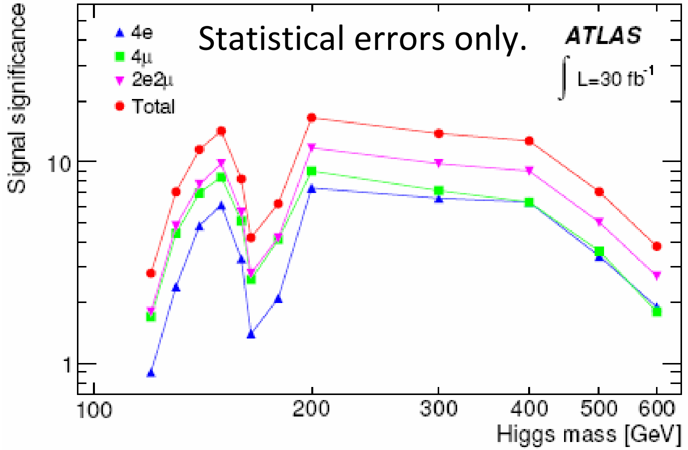
Similar results for ATLAS and CMS

Background estimated in sidebands → low systematic uncertainties

H →ZZ→4ℓ





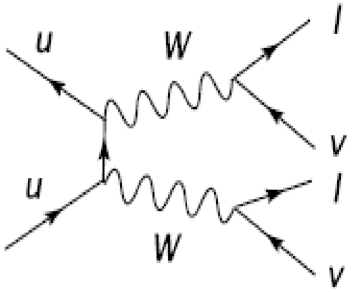


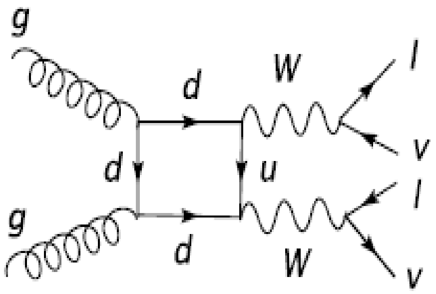
5s potential Higgs discovery for the three different subprocesses

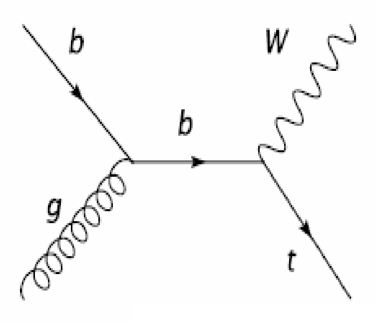
- without systematics uncertainties (ATLAS and CMS)
- and with systematics included (CMS).

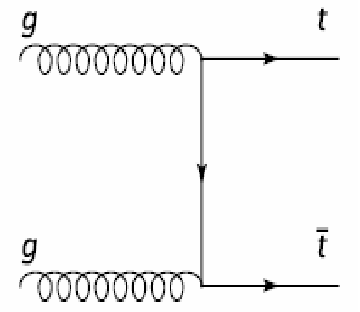
H → WW

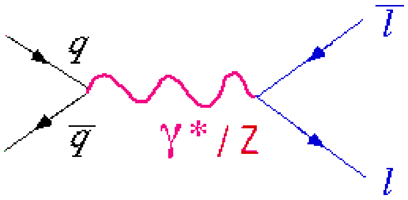
- Particularly interesting for $2M_W<M_H<2M_Z$ (but its sensitivity extends also to lower masses) where all other decay modes are suppressed. Signature is 2μ, 2e, eμ + E_T^{miss}.
- No mass peak ➔ use transverse mass.
- High background, needs to be well understood: WW, Wt, ttbar, Z→2l, …
- Reconstruction:
  - Two processes: 0 jets (gg-fusion) or 2-forward jets (VBF).
  - Trigger : single or double lepton selection
    - ATLAS: 1μ20i or 1e25i;
  - Offline: select events with exactly two isolated (tracking and calorimeter) opposite sign primary leptons and E_T^{miss}.



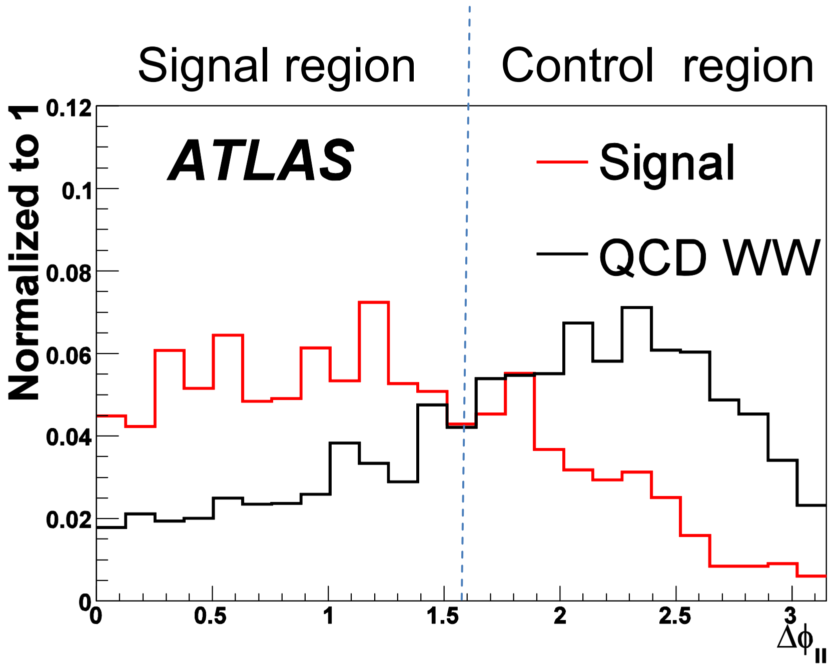


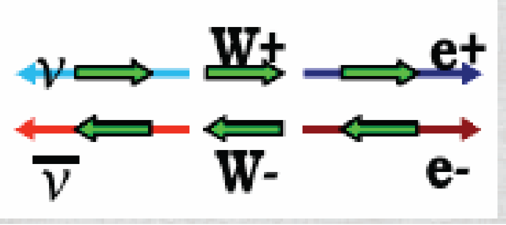






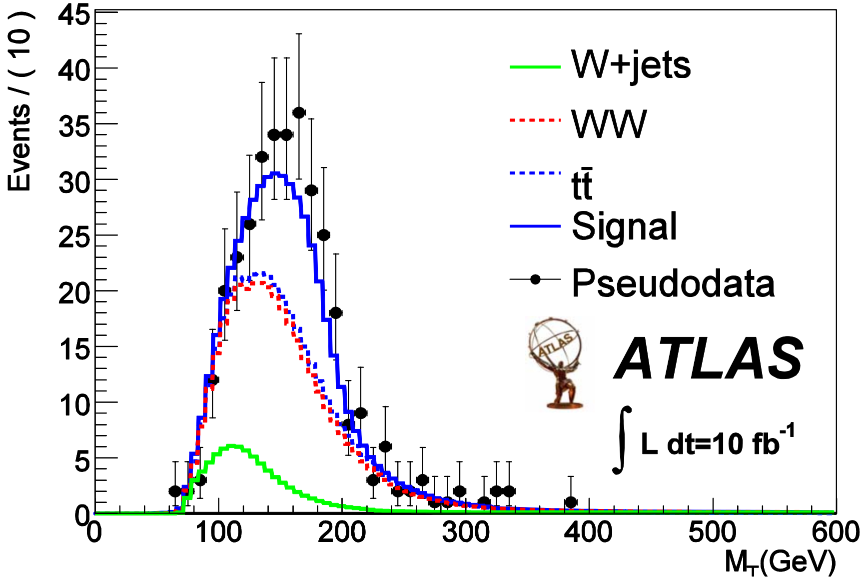
H → WW





Study the phi-opening angle of the two leptons (WW+0Jets, only preselection cuts applied)

The challenge: we need precise knowledge of the backgrounds: fit the transverse mass and the transverse momentum of the candidates in two bins of the dilepton opening angle Δϕ in the transverse plane; account for the ratio of the background in the two regions → extract the signal and background mixture in the signal region.

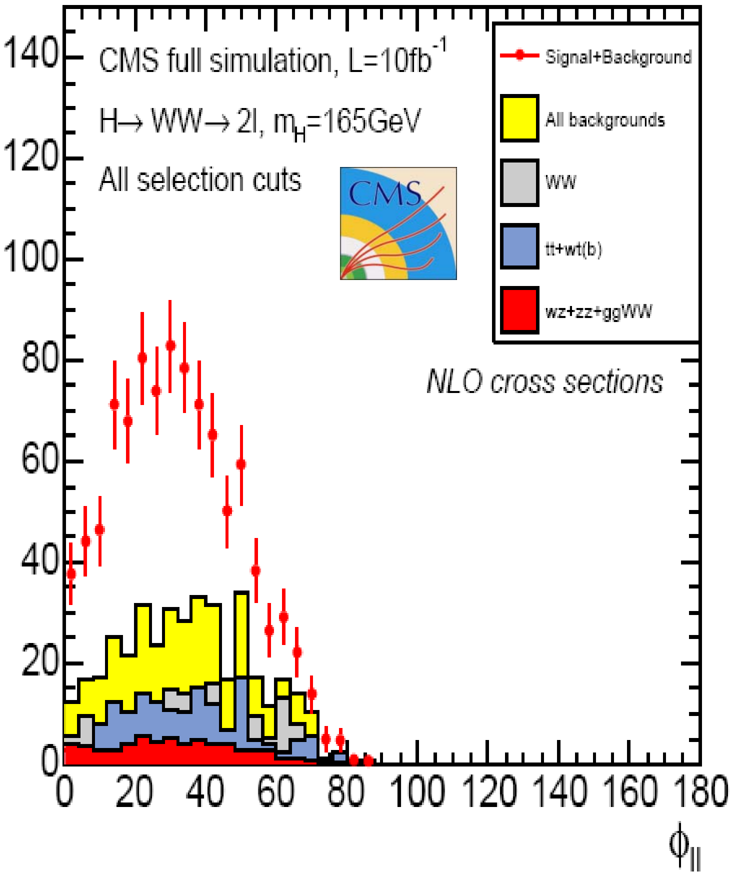


The transverse mass distribution in the region $\Delta\phi<1.575$ and $p_T^{WW}>20$ GeV.

H →WW

CMS: Final selection μμ + μe + ee channels

angle between two leptons

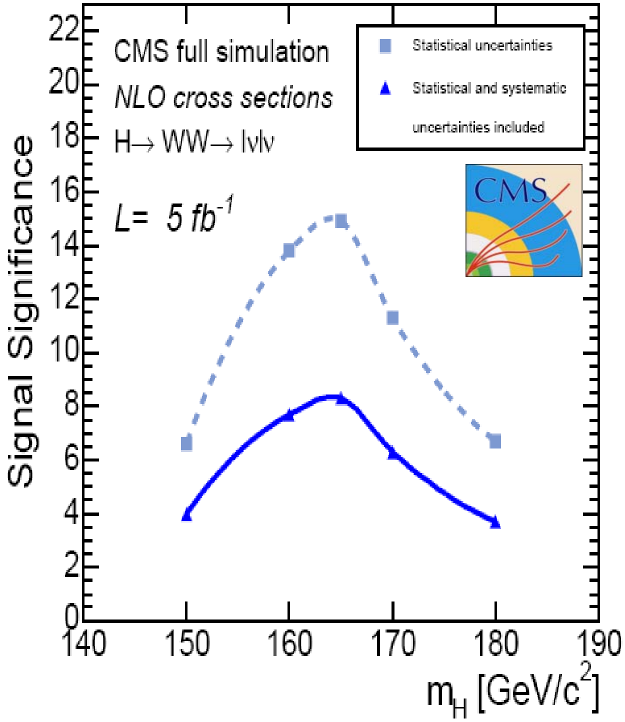


l = e , μ , τ	σ_{NLO} x BR (pb)	Rate / fb^{-1}
H→WW→ll (160 GeV)	2.34	**42**
H→WW→ll (165 GeV)	2.36	**46**
H→WW→ll (170 GeV)	2.26	**33**
qq→WW→ll	11.7	12
gg→WW→ll	0.48	3.7
tt→WWbb→ll	86.2	9.8
tW→WWb→ll	3.4	1.4
ZW→lllν	1.6	0.5
ZZ→llνν	1.5	0.35
Sum backgrounds	105	**28**

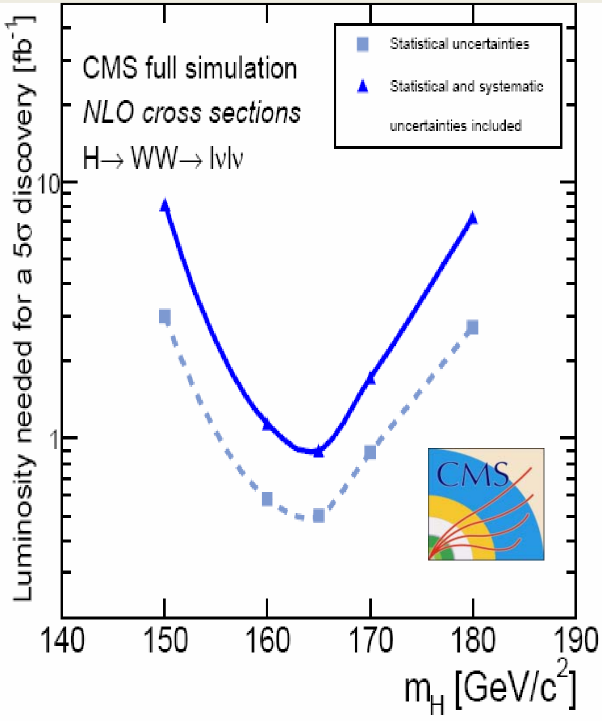
H → WW

CMS

Signal significance



Luminosity for discovery at 5σ



Estimated background uncertainties:

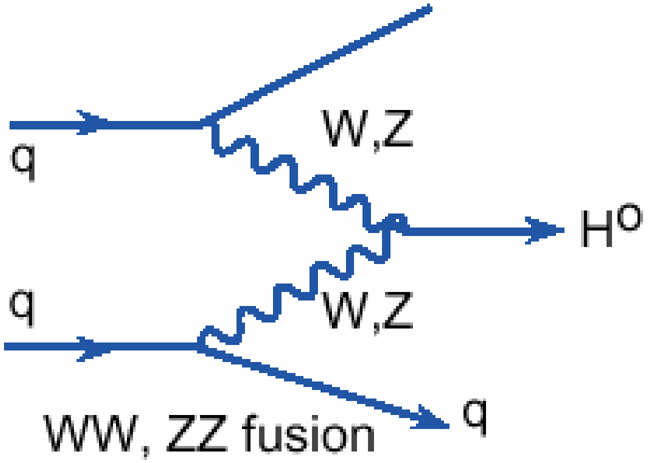
- **tt from data: ±16% at 5 fb^{-1}**
- **WW from data: ±17% at 5 fb^{-1}**
- **Wt from theory: ± 22%**
- **gg → WW from theory: ± 30%**

ATLAS

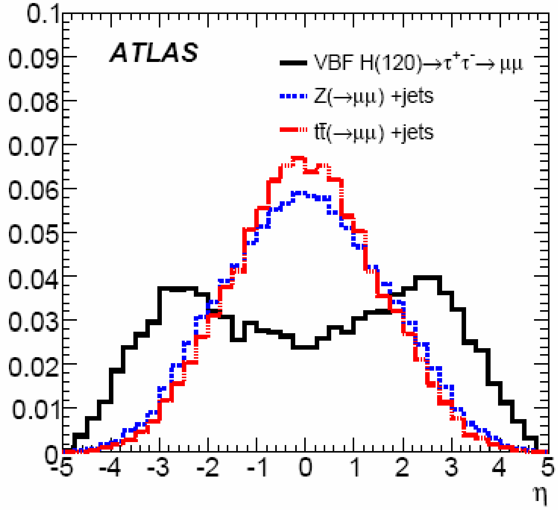
Significance studies are under finalization, and results will be available soon

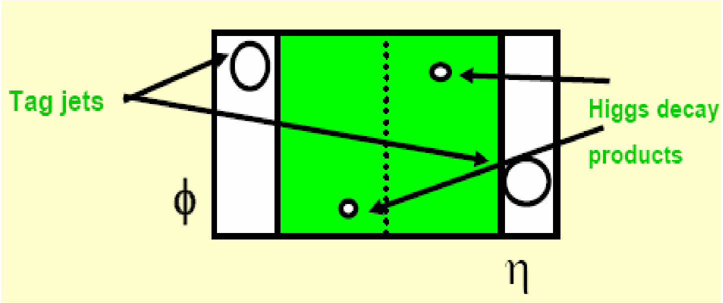
VBF qqH

Two distinct signatures:
1.Two forward “tag” jets (large η separation with high-p_T) with large M_{jj}
2.No jet activity in the central region (between the two ta jets): jet veto



Typical cuts require:
- Tag jets are assumed to be the highest E_T jets in opposite hemispheres, with E_T>~40 GeV, $\Delta\eta_{jj}$>~4, M_{jj}>500-1000 GeV.
- Higgs decay products between tag jets in η
- No additional jet activity in the event: central jet veto.





Channels:

qqH $\rightarrow$ qq$\gamma\gamma$

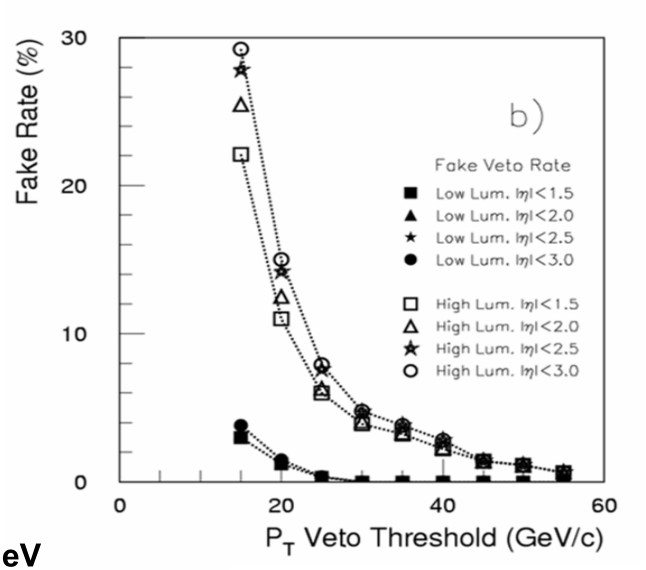
qqH $\rightarrow$ qqWW$^{(*)}$, WW$^{(*)}$ $\rightarrow$ lν lν and lν jj

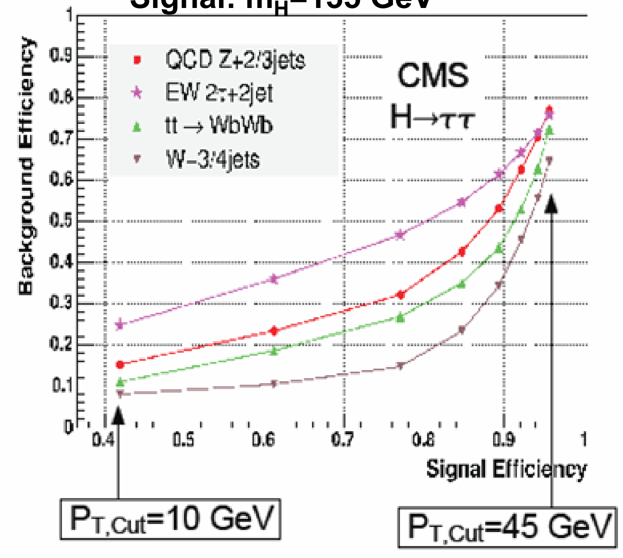
qqH $\rightarrow$ qq$\tau\tau$, $\tau\tau$ $\rightarrow$ l$\nu\nu$-l$\nu\nu$, l$\nu\nu$-had ν, and had-had

VBF qqH

Experimental issues:

- **Good efficiency** for the reconstruction of **forward jet** is required.
- There are also uncertainties on the **robustness of the jet veto** with respect to radiation in the underlying event and to the presence of pile-up. So far VBF channels have been studied at low luminosity only.
- Good tau-pair **mass resolution**.



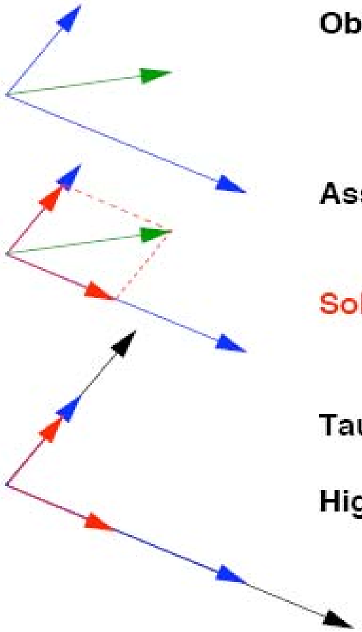


VBF qqH→ττ

Interesting channel for $M_H<150$ GeV: increases sensistivity to low mass H:

- **Trigger:** single lepton trigger + tau trigger
- **Background:** Z→tt+jets, Z→ll+jets, W+jets, tt,…
- **Analysis:**
  - Besides the VBF cuts, select the primary isolated electron, together with a M_T(l-E_T^{miss}) cut to reduce the W background.
  - τ jet identification important: use tracking and calorimeter information.
  - The H mass can be reconstructed using the collinear approximation: the τ mass is neglected and it is assumed that
  - the ν direction coincides with the visible decay products of the τ's.

Mass Reconstruction:



Observe
missing transverse momentum
and visible Tau–decay products

Assume Tau decay products
collinear with original Tau

Solve 2 linear equations
for the neutrinos

Taus can be reconstructed

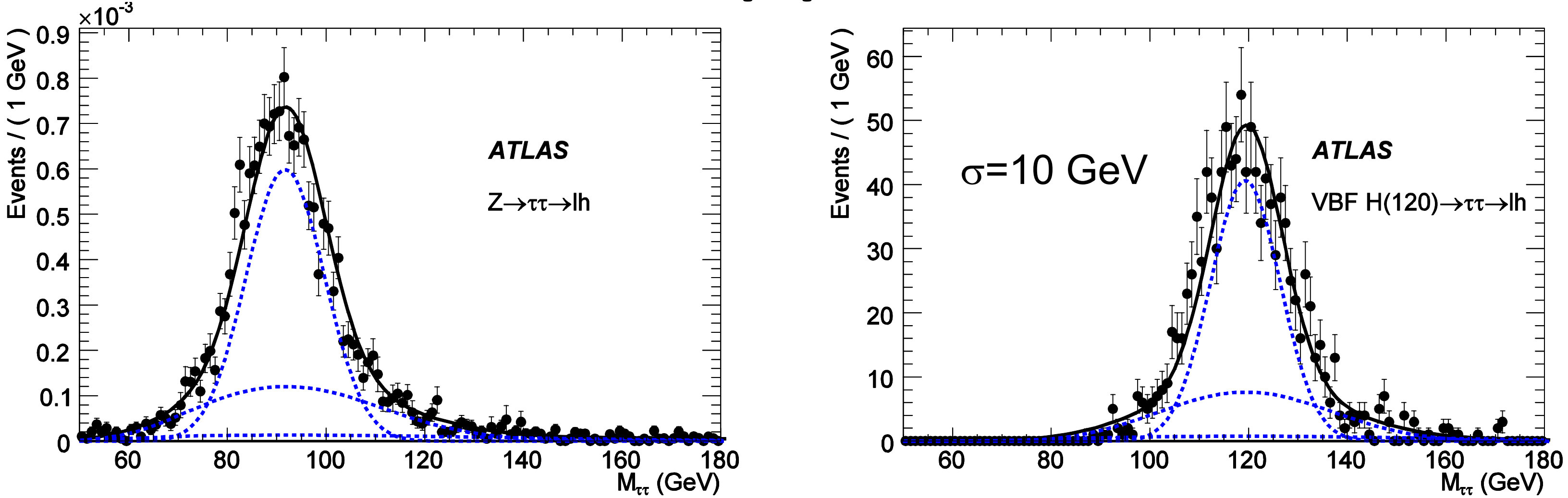
Higgs can be reconstructed

$$M_{\tau\tau} = \sqrt{2(E_h + E_{\nu h})(E_l + E_{\nu l})(1 - \cos\theta_{\tau\tau})}$$

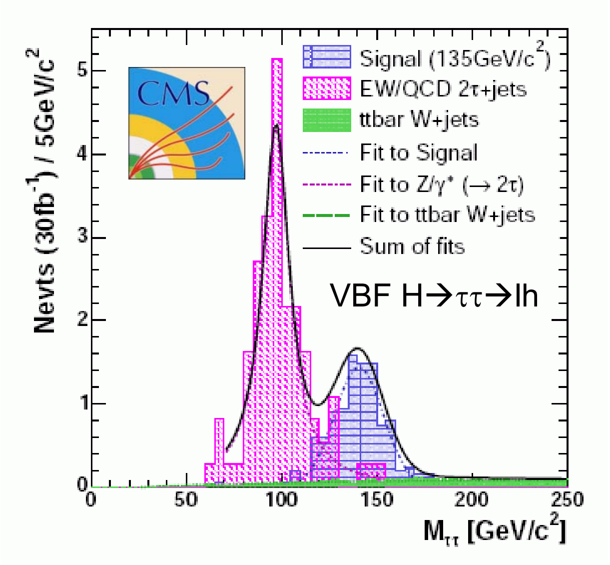
is equivalent to $M_{\tau\tau} = \frac{M_{ll}}{\sqrt{x_{\tau l} x_{\tau h}}}$

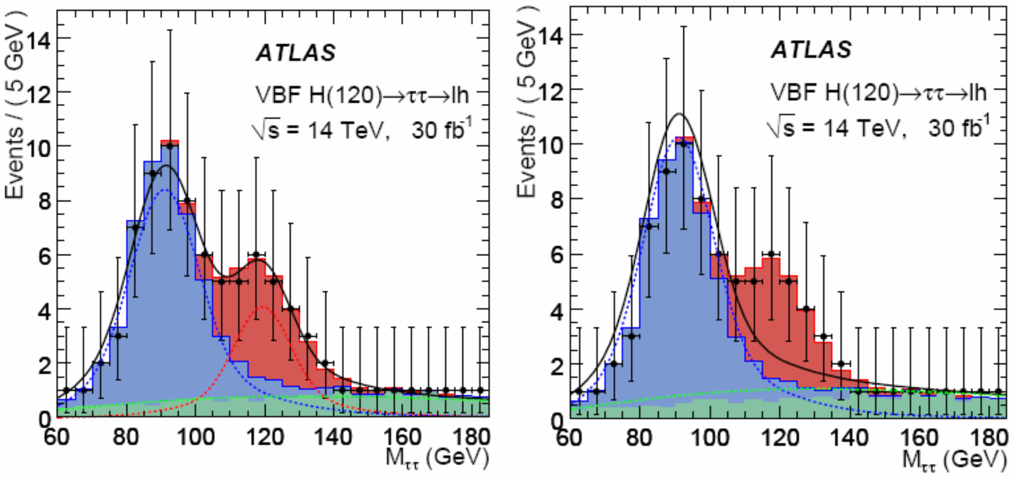
only when $0 < x_\tau < 1$

VBF qqH→ττ

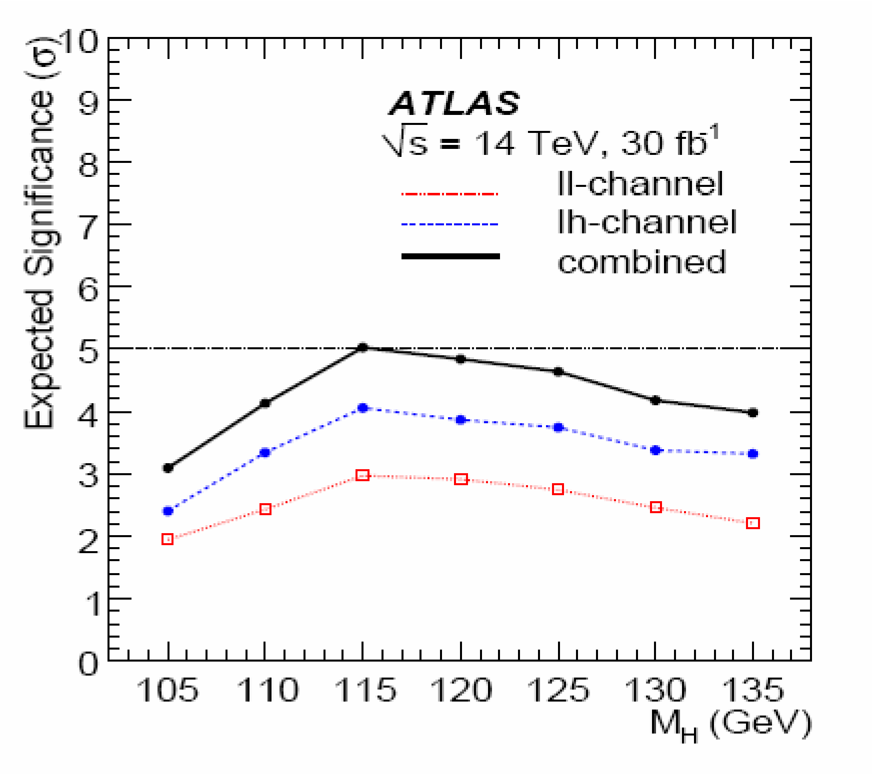


pure Monte Carlo samples of *Z →tt and* signal (*MH = 120 GeV) in the lh-channel, respectively.*

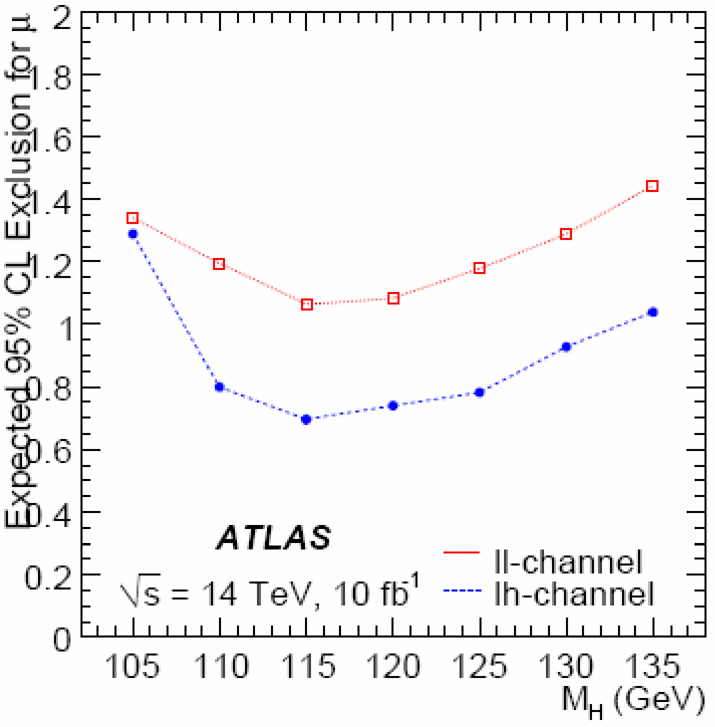




VBF qqH→ττ

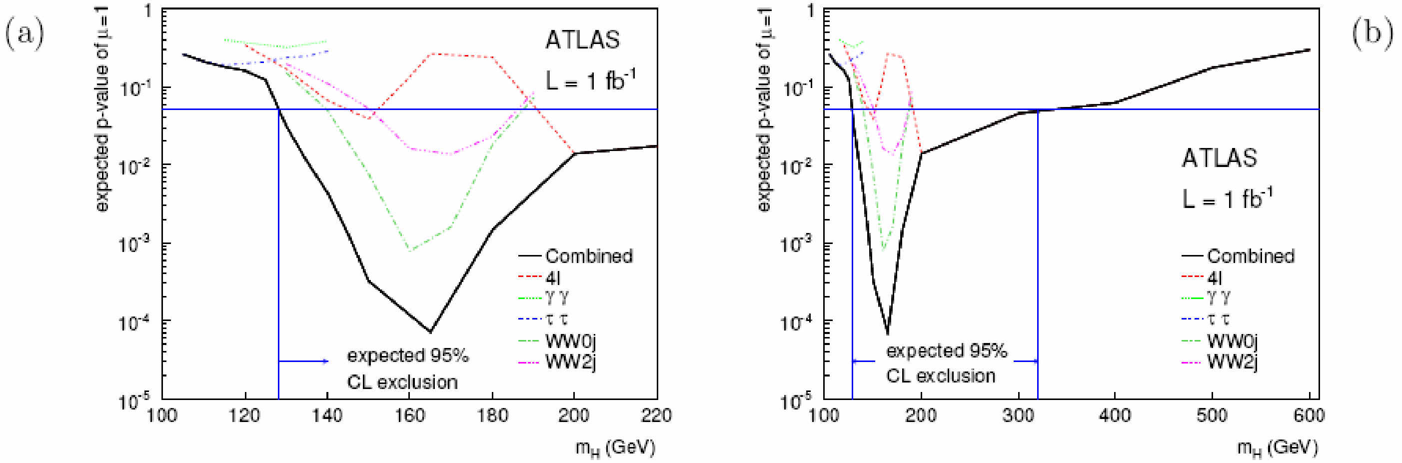


Expected signal significance for several masses based on fitting the $m_{\tau\tau}$ spectrum. Background uncertainties are included

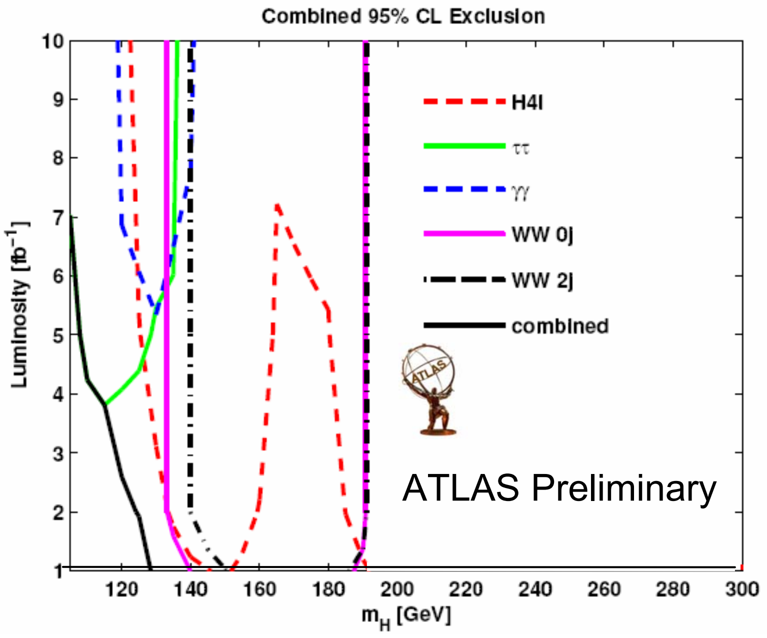


Expected 95% exclusion of the signal rate in units of the standard model expectation, m, as a function of the Higgs boson mass for the *ll and lh-channels with 10 fb−1 of data. The exclusion* takes into account the uncertainty on the signal efficiency.

Higgs Channels Combination

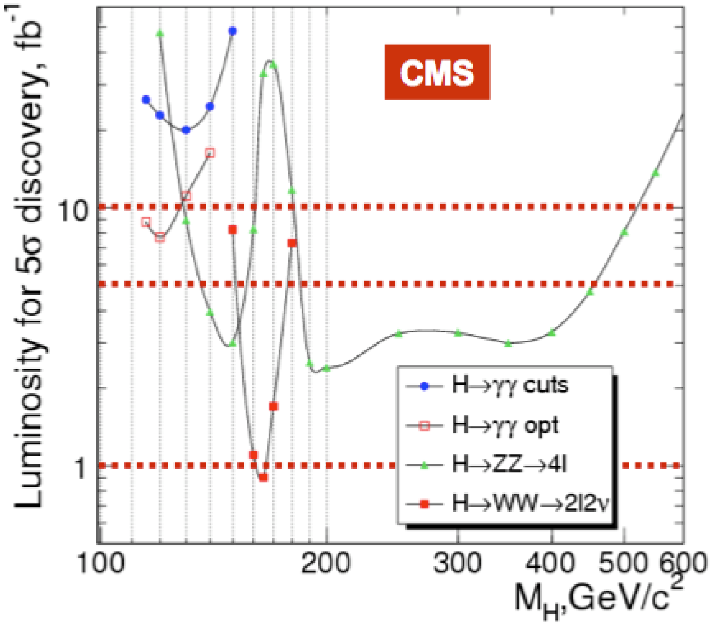


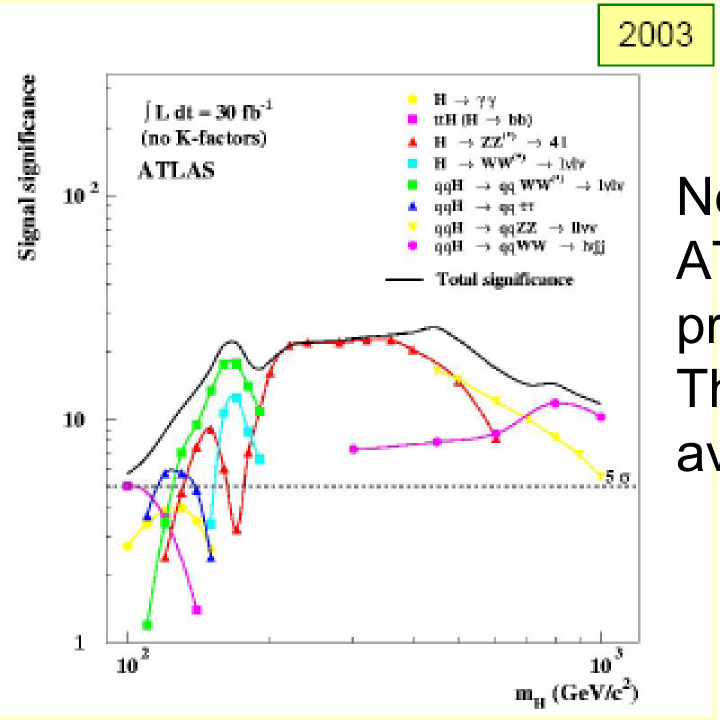
The median p-value obtained for excluding a SM Higgs Boson for the various channels as well as the combination for (a) the lower mass range (b) for masses up to 600 GeV.



The expected luminosity required to exclude a Higgs Boson with a mass mH at the 95% Condence Level.

Higgs Channels Combination




2003

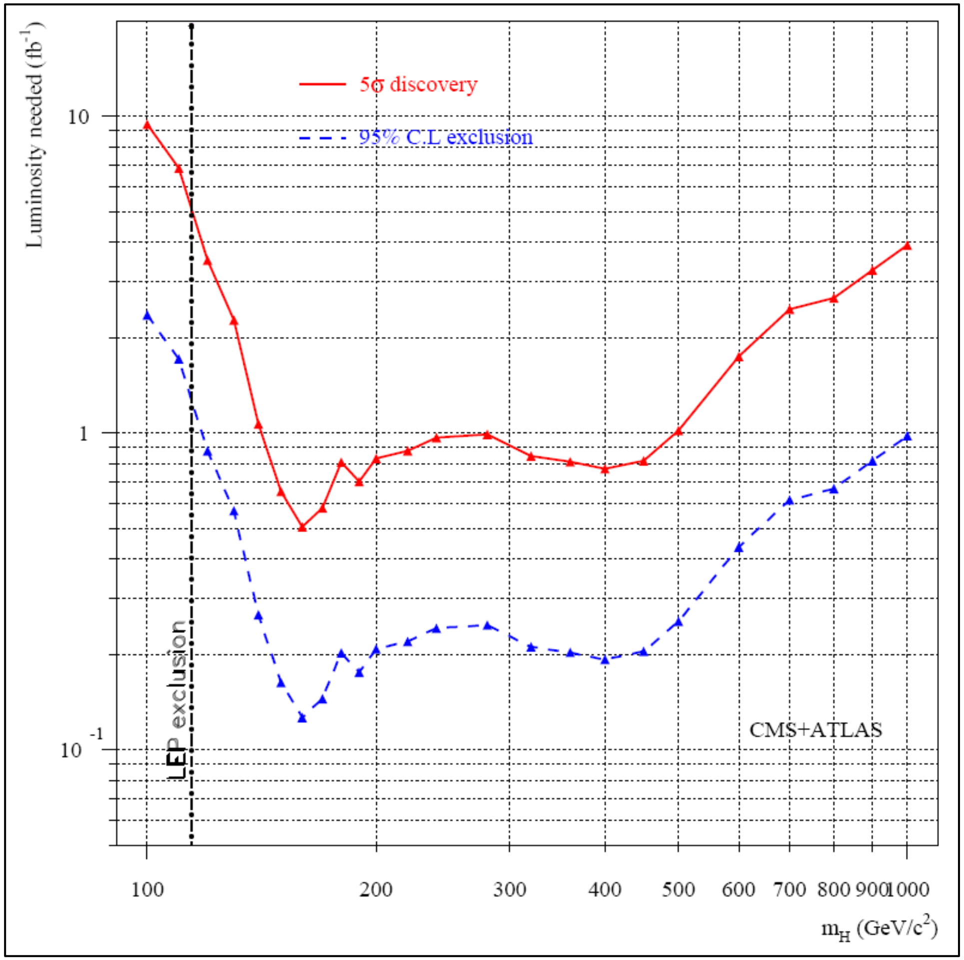
New results from ATLAS are in preparation. They will be available soon

Full mass range can already be covered after a few years at low luminosity

Several channels available over a large range of masses

Higgs Channels Combination

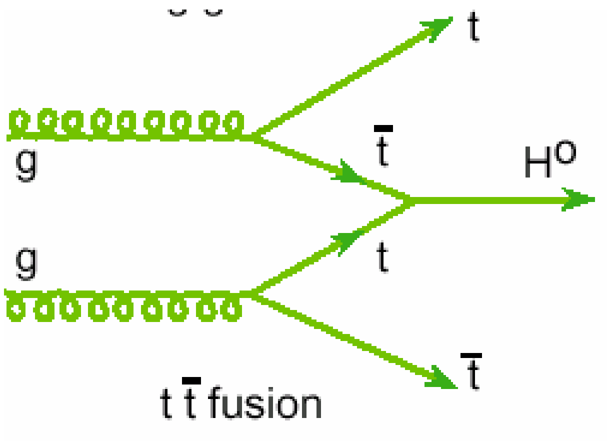
Luminosity required for a 5σ discovery or a 95% C.L. exclusion



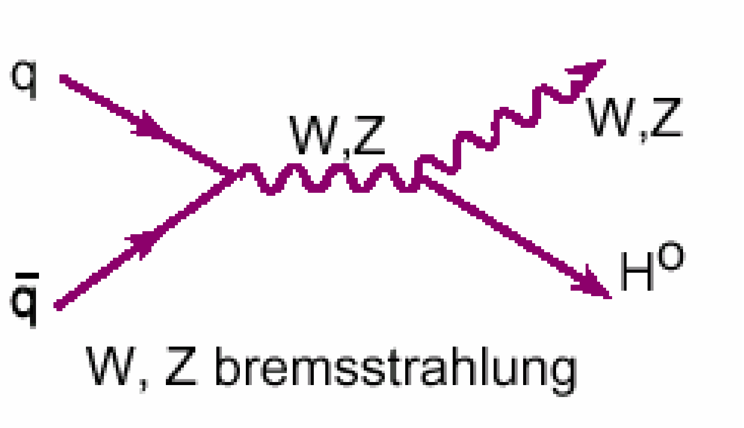
Combination plot based on past ATLAS and CMS studies: Hopefully it will be updated very soon

From this plot we see:
about 5 fb^{-1} needed for the discovery
< 1 fb^{-1} for a 95% C.L. exclusion

Higgs associated production



$t\bar{t}$ fusion



W, Z bremsstrahlung

pp → WH, ZH, ttH with W → $l\nu$, Z → ll or Z → $\nu\nu$

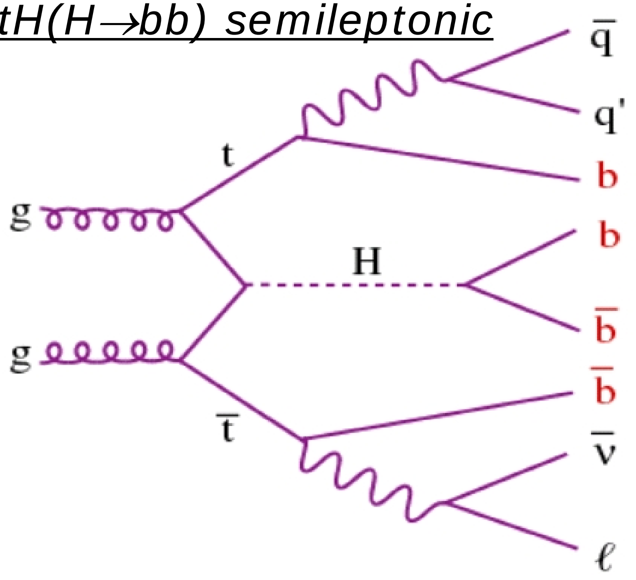
Leptons from W, Z and t→Wb→$l\nu$b can provide trigger and discrimination from background. Provide useful channels with higher integrated luminosity (~100 fb^{-1}).

An example:

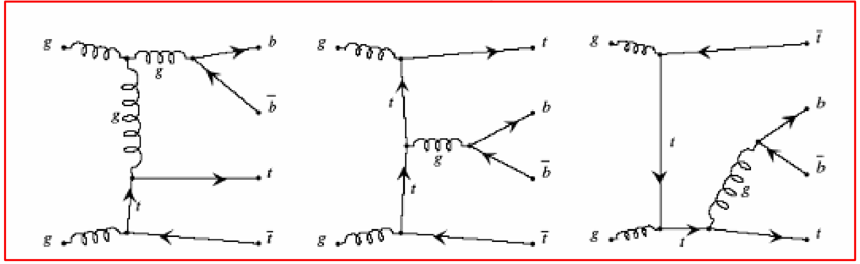
ttH→ttbb

- ttH(→bb): important channel for light Higgs boson
- Trigger: all hadronic final state has higher branching fraction, but the trigger is very difficult, if not impossible…: → both experiments look for inclusive top semileptonic decays to isolated electrons or muons;
- Reducible Background:
  - tt(+jj)
    - Dominant background;
    - b-tagging must be optimized to have strong light jet rejection
  - WWbbjj, Wjjjjjj
    - discriminated by reconstructing tt pairs
- Irreducible background:
  - ttbb (EW/QCD)
    - slight differences in kinematic properties w.r.t ttH
- Offline analysis:
    - isolated lepton
    - missing energy
    - ≥ 6 jets, ≥ 4 jets b-tag
      - need large b-tagging efficiency: signal $\alpha(\varepsilon^4_b)$
  - In general high jet multiplicity:
    - Large contribution of ISR/FSR; large uncertainties

ttH(H→bb) semileptonic



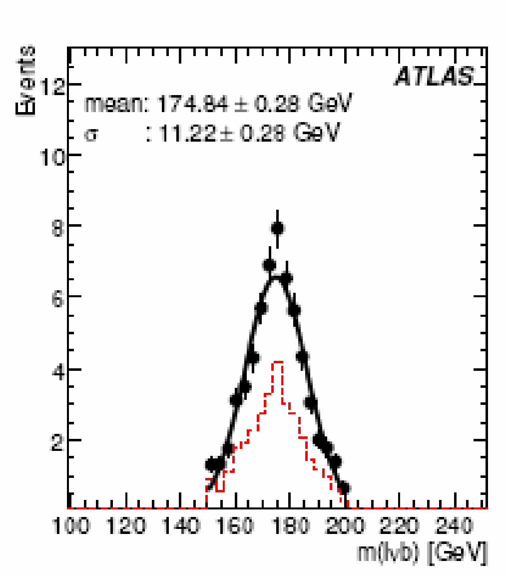
ttbb Production diagrams via QCD



ttH→ttbb

- After a first optimistic evaluation on the TDR:
    - Updating pdf: 20% smaller cross sections
    - Matrix element based Monte Carlo for ttbb background
        - $\Rightarrow$ higher jet multiplicity

- Two likelihood functions used:
    - Fast simulation analysis
    - pairing likelihood used to associate b quarks from top decay
    - Second likelihood to discriminate ttbb
        - ttH more energetic
        - different in angular distributions for b coming from Higgs decay



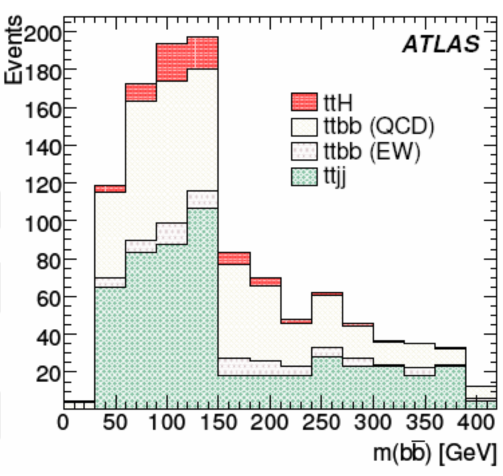
b-tagging performance

ε_b = 65 %

R_c = 7

R_l = 100

Reconstructed invariant mass spectrum for selected leptonic top quark candidates in the signal sample. The dotted red line indicates the candidates formed by assigning the correct *b-jet* to the top quark being considered. The distribution is normalized to 30 fb^{-1}.



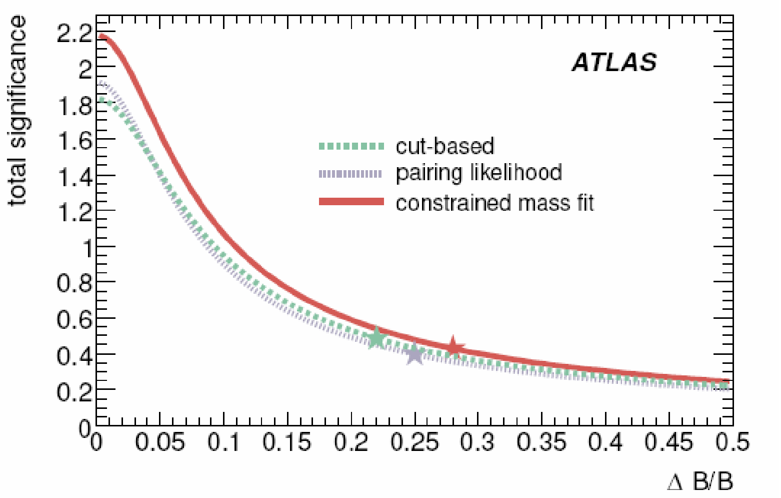
Reconstructed invariant mass spectrum signal and background after the pairing likelihood selection. The distribution is normalized to 30 fb^{-1}.

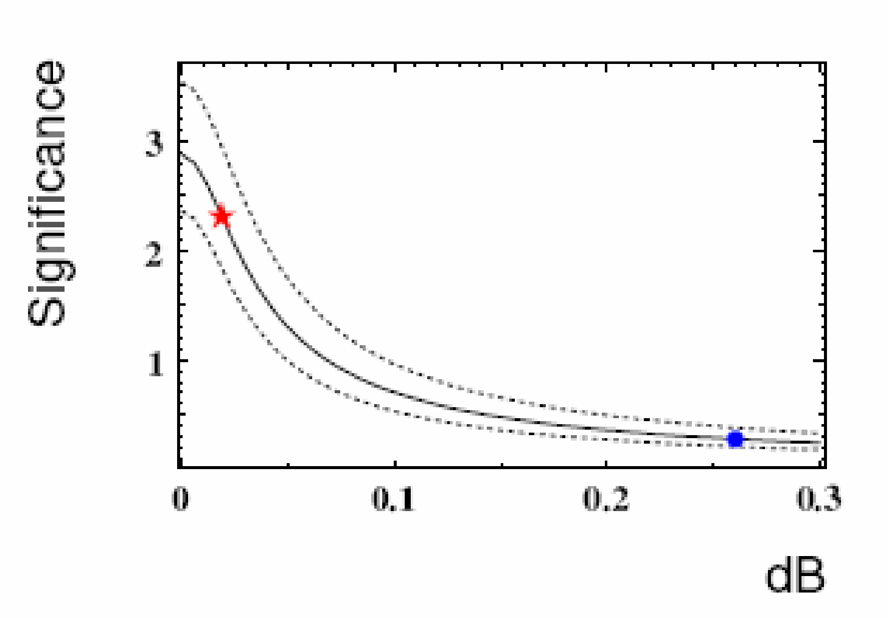
m_H = 120 GeV, L = 30 fb^{-1}

ttH→ttbb

Significance in ATLAS for L=30 fb^{-1}.

Significance in CMS for L=30 fb^{-1}.





A n uncertainty on the overall background smaller than 5% is needed to have the "observation" of the of the process ttH→ttbb: a challenge for both ATLAS and CMS

Towards data taking…

Conclusion

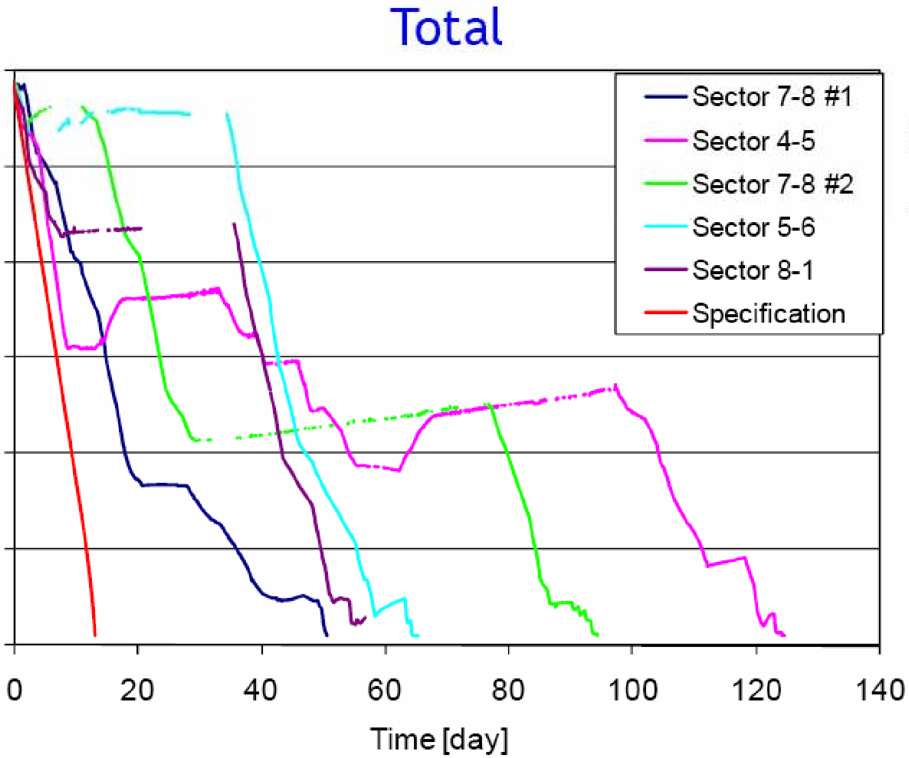
- The Large Hadron Collider will start collisions (although at a reduced energy) in the second half of this year. Fully energy and “low” luminosity in 2009.
- ATLAS and CMS are finalizing the commissioning of the detectors with cosmics: almost ready to fully close the apparatus in view of the data taking.
- These experiments are well set up to explore the existence of a Standard Model (or MSSM) Higgs bosons …... and are well prepared for unexpected scenarios
- The full Standard Model mass range can be covered; exclusion limits can be set with a very modest luminosity.

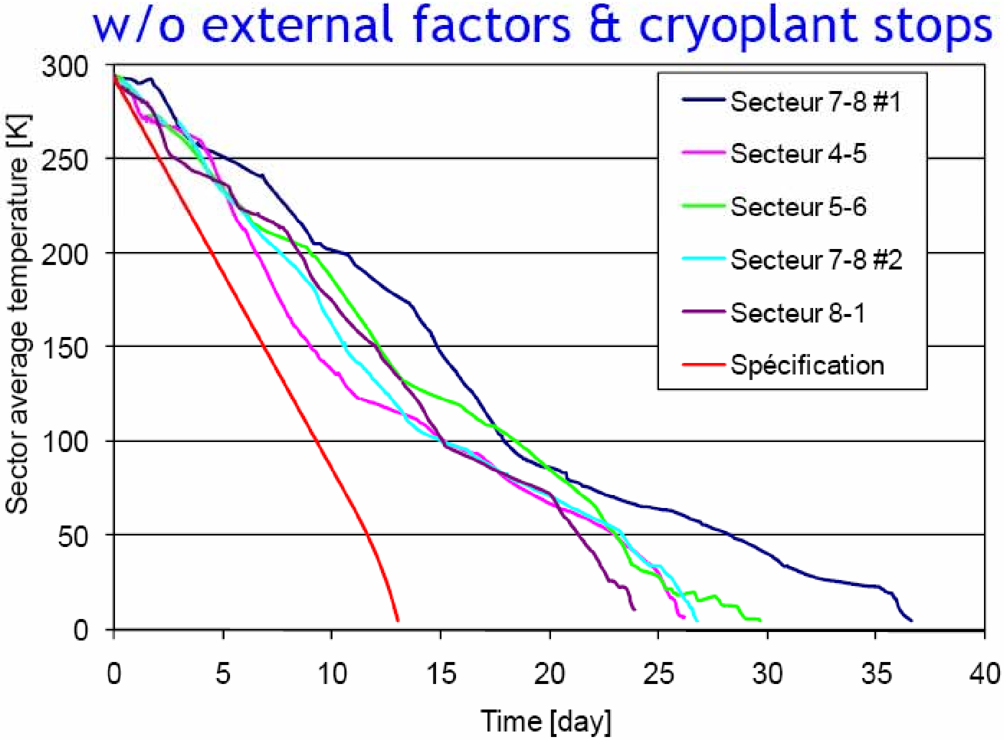
Backup slides

Duration of the cool down

Cool-down time hampered by:

- external factors (leaks, electrical short-circuits, electrical control plateaus),
- cryogenic stops (utility loss, cryogenic problems),
- cryogen logistics management (week-ends, nights…),
- cryoplant and tunnel cooling loops tuning and limitations.


Total


w/o external factors & cryoplant stops

Room for improvement !

H→4l

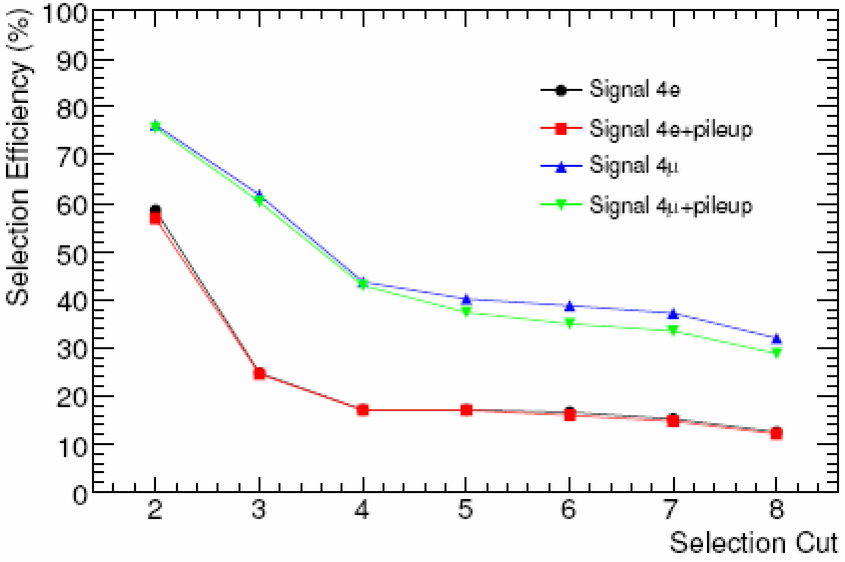
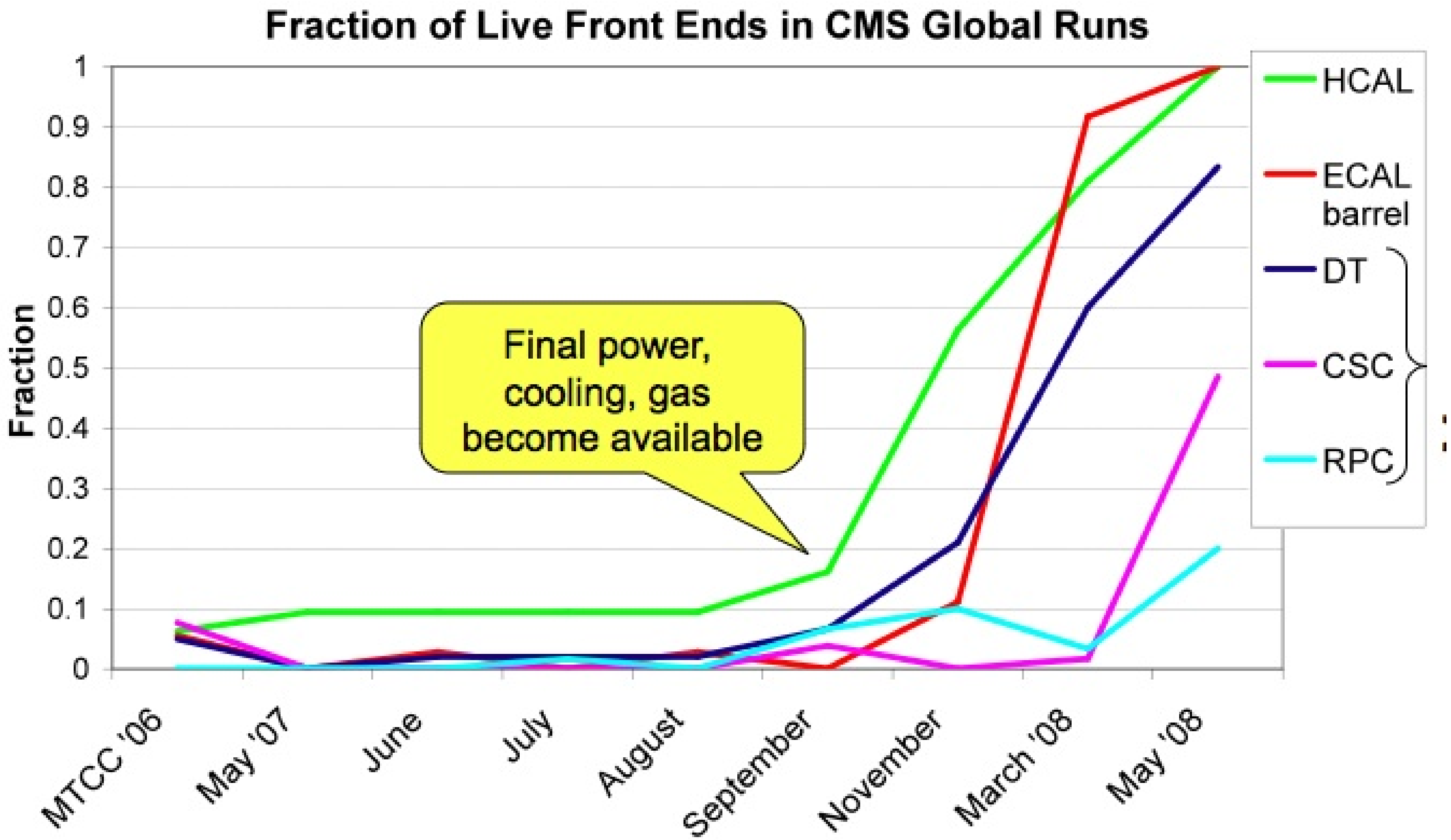


Figure 31: *Fraction of selected events with and without pile-up and cavern background, for the cuts in Tables 7 and 8 (130 GeV H→4e and 4μ analyses).*

“Global” runs participation vs time


Fraction of Live Front Ends in CMS Global Runs

Final power, cooling, gas become available

All subsystem DAQ able to sustain 100 KHz instantaneous Level 1 rate. In last global cosmic run in May data taking routinely lasted more than 4 hours without problems with 250 Hz logging rate after High Level trigger. Data transferred to Tier0 (all Tier1’s and some Tier2’s and reconstructed in real time

Measurement of SM Higgs properties

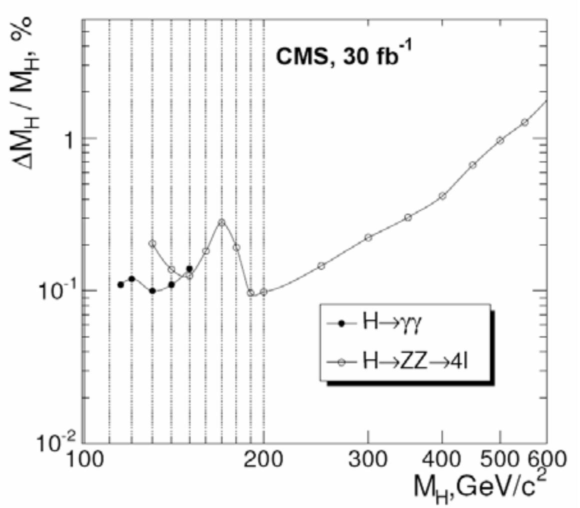
Mass measurement

- Best channels for this measurement are H→γγ and at higher masses H→4l.

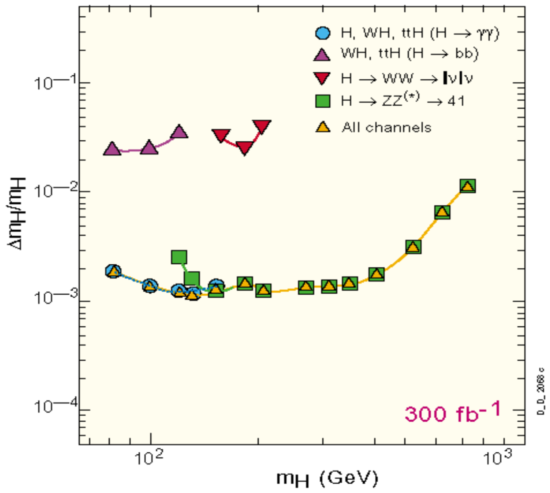
- CMS estimates a precision <0.3 % up to 350 GeV (stat error only) with 30 fb^{-1}

- ATLAS estimated about 0.1 % up to 400 GeV with 300 fb^{-1} including sys errors.

- The precision will be limited by the uncertainty on the lepton and photon energy scale, which is expected to be at the level of 0.1%



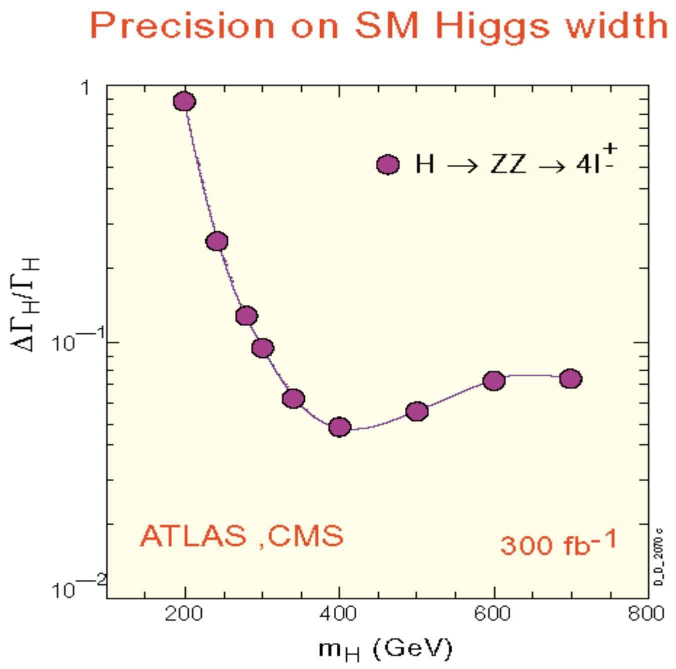
Precision on SM Higgs mass



Measurement of SM Higgs properties

Width measurement

For small H masses, the intrinsic H with is negligible with respect to the experimental resolution. Direct measurement with reasonable accuracy can be performed only above ~200 GeV (better than 10% for M_H>300 GeV with 300 fb^{-1})



Spin and CP

In the SM, H has $J^{PC}=0^{++}$

If $H\rightarrow\gamma\gamma$ or $gg\rightarrow H$ are established, J=1 can be excluded. This and other J^{PC} combinations can be also excluded studying angular correlations in H→4l decays.

Measurement of SM Higgs properties

Measurement of couplings

Likelihood fit to expected number of events in all observable channels. Include sys errors from detector effects, luminosity, background normalization, cross sections.

Concentrating on low Higgs masses (<200 GeV), several measurements are possible, depending on how many assumptions are done:

1. Assuming Higgs have spin 0, $\sigma \cdot BR$ can be measured
2. Assuming there is only one H boson, can fit ratio of widths Γ_i/Γ_W, in this case normalized to the Γ of H→WW
3. Assuming there are no new particles in loop and no strong couplings to light fermions, can obtain ratio of (5) couplings
4. Assuming that $\Gamma_V<\Gamma_V^{SM}$, can “measure” absolute couplings