The ATLAS Experiment at the LHC
-status and expectations for physics -

- ATLAS Status and Commissioning
- Expected first physics with ATLAS
- Prospects for 1, 10 and 30 fb^{-1}
  - Top
  - Higgs Bosons
  - New Physics (a few examples)

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The role of the LHC

1. Explore the TeV mass scale

- What is the origin of the electroweak symmetry breaking ?

- The search for “low energy” supersymmetry

- Other scenarios beyond the Standard Model
- …….

Look for the “expected”, but we need to be open for surprises

2. Precise tests of the Standard Model

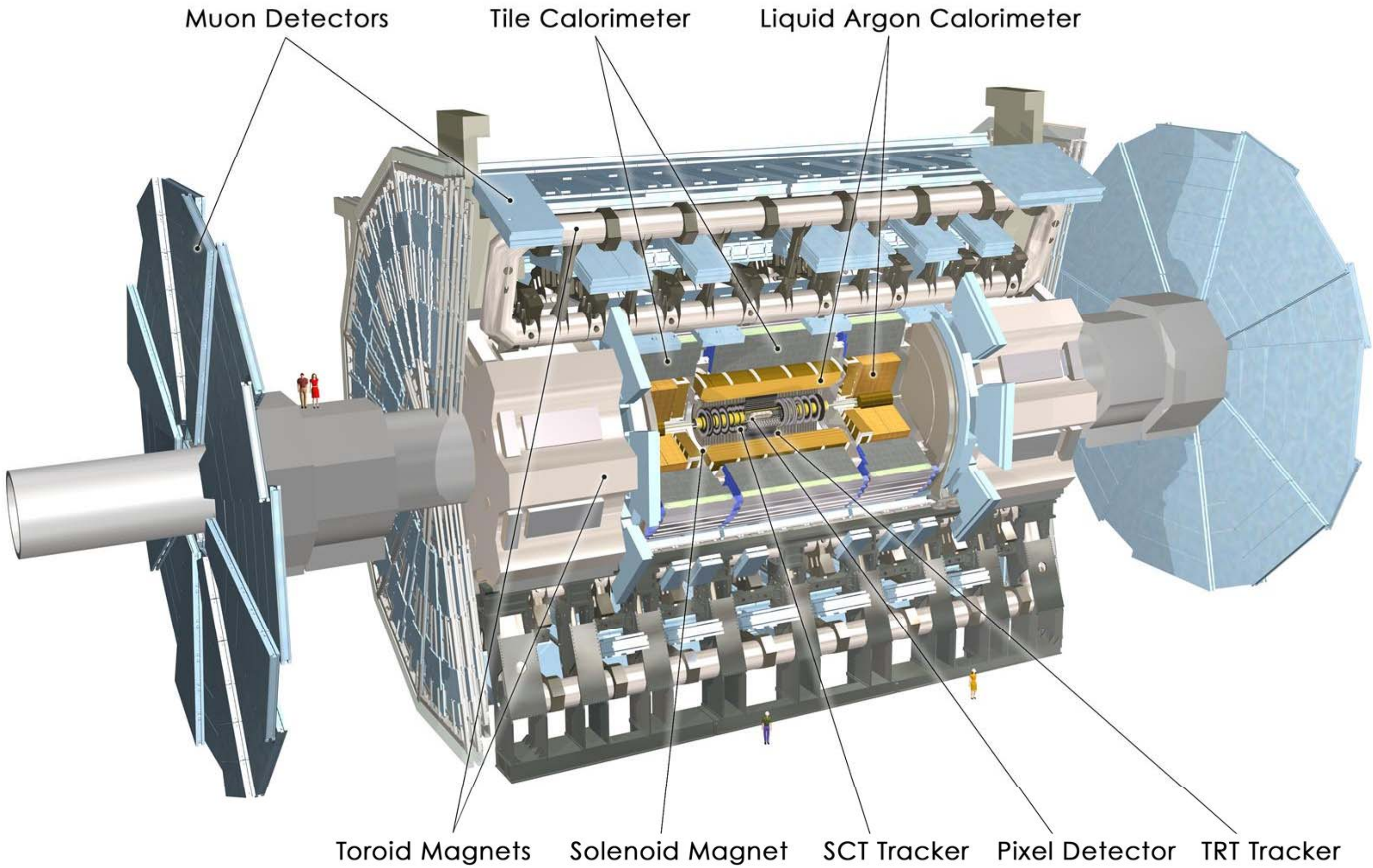
- There is much sensitivity to Physics Beyond the Standard Model in the precision area

- Many Standard Model measurements can be used to test and to tune the detector performance

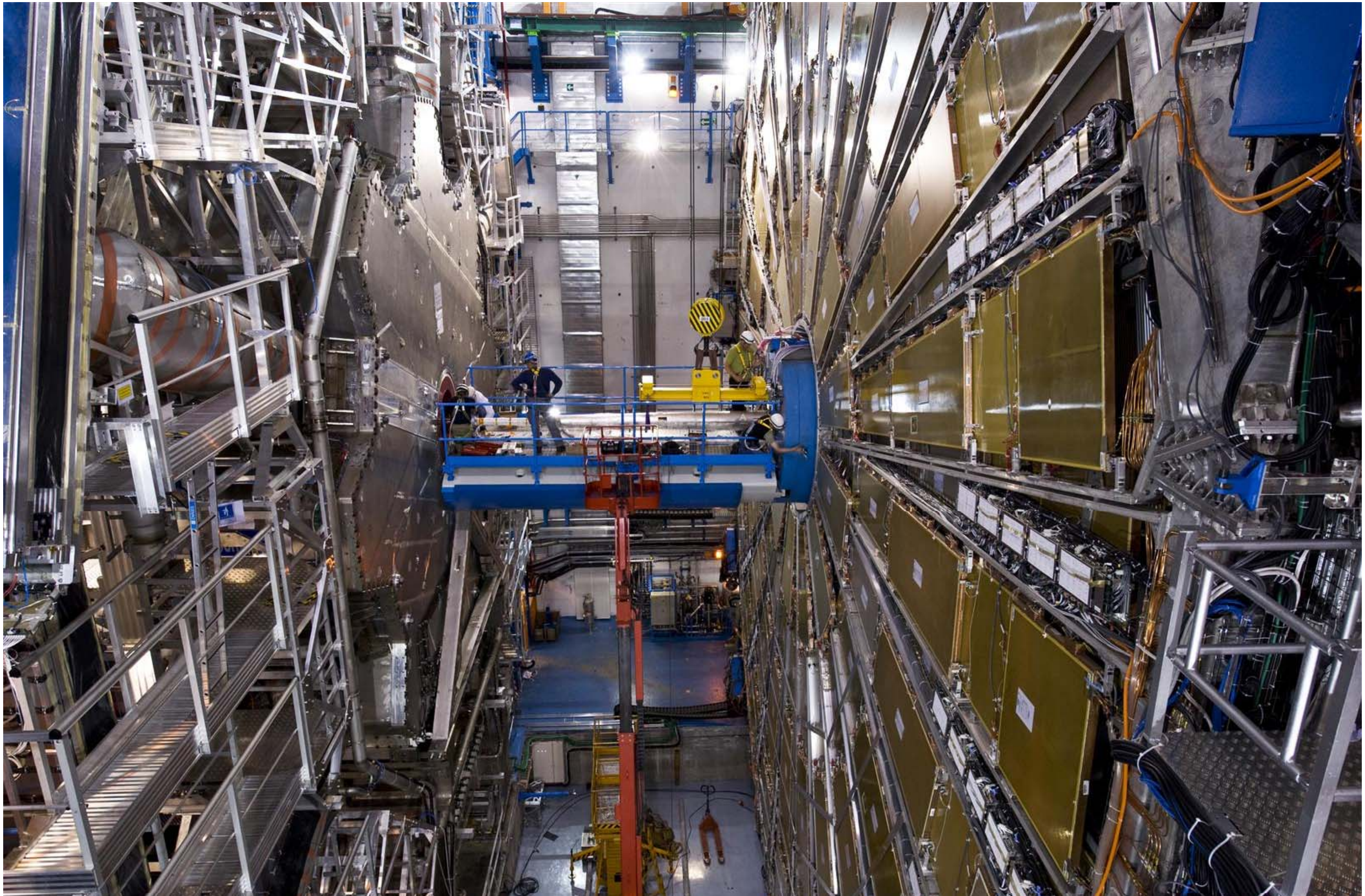
This Talk (ATLAS):
- Top Quark Physics
- Higgs Searches
- A few Exotica

J. Nash (CMS):
- Standard Model (QCD, el.weak)
- SUSY
- More Exotica

The ATLAS experiment

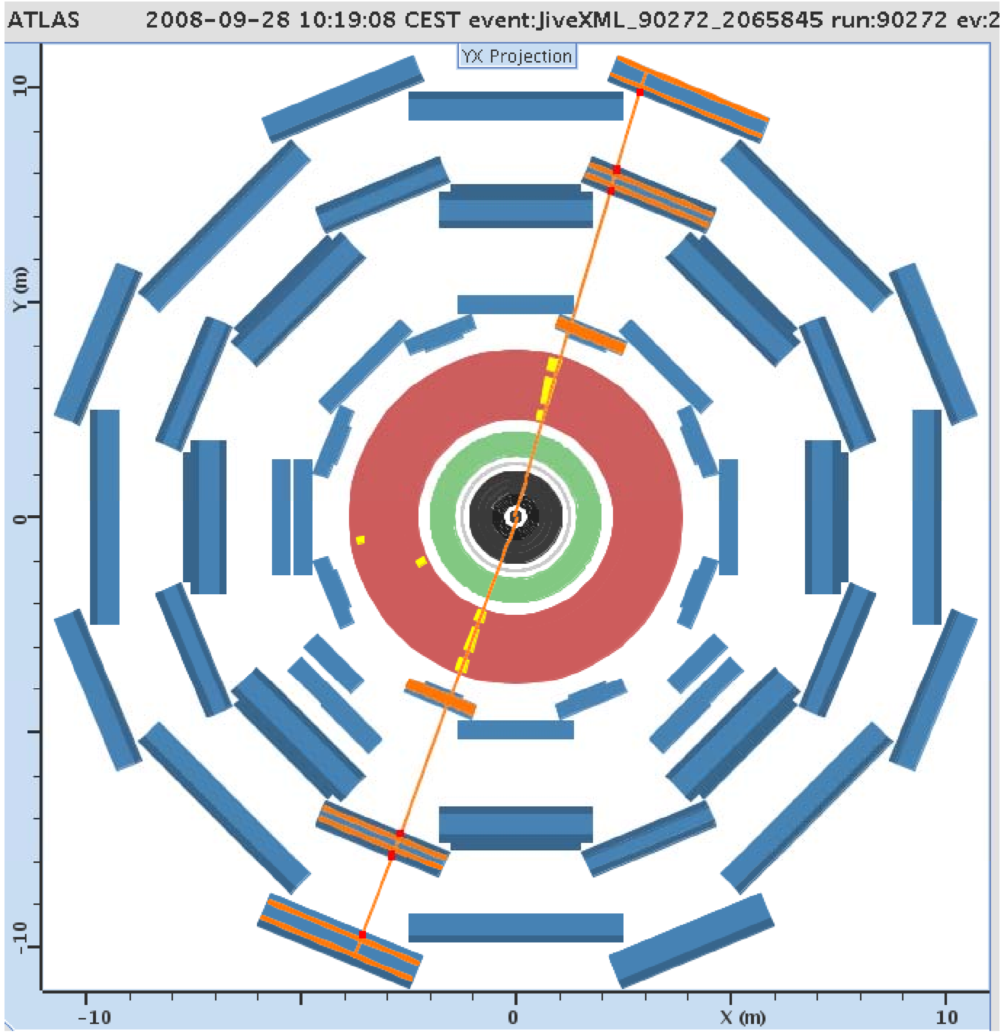


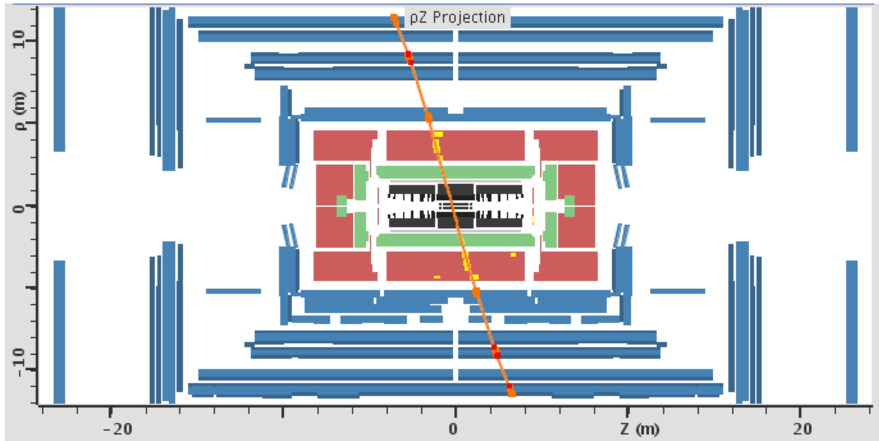
Diameter	25 m
Barrel toroid length	26 m
End-cap end-wall chamber span	46 m
Overall weight	7000 Tons

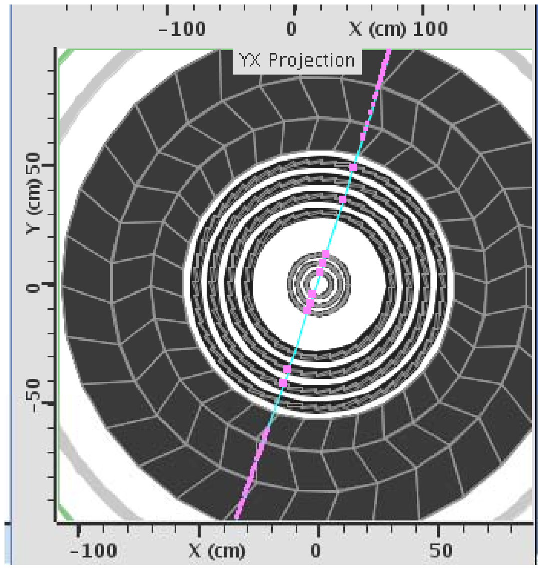


A historical moment:
Closure of the LHC beam pipe ring on 16th June 2008
ATLAS was ready for data taking in August 2008

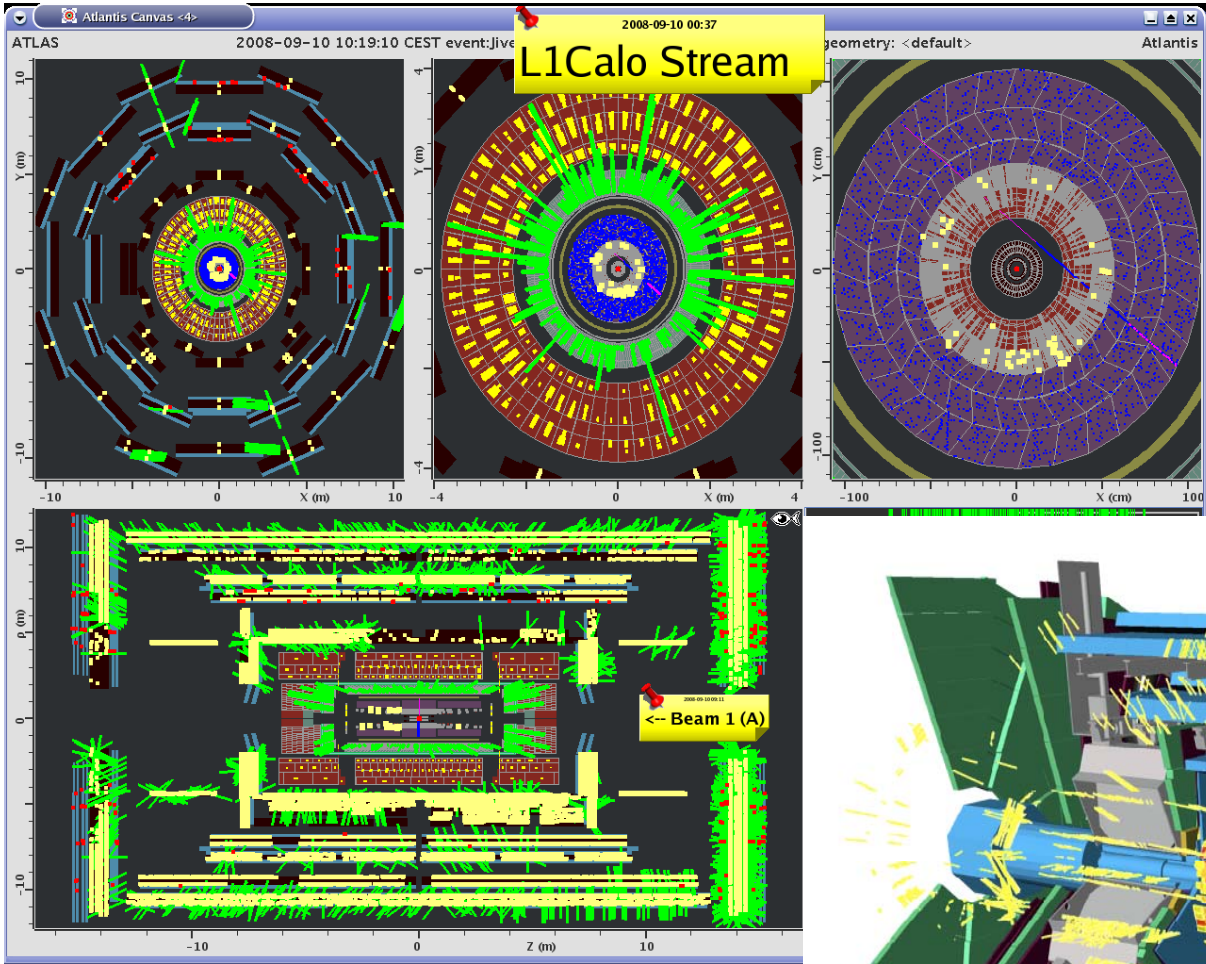
ATLAS Commissioning



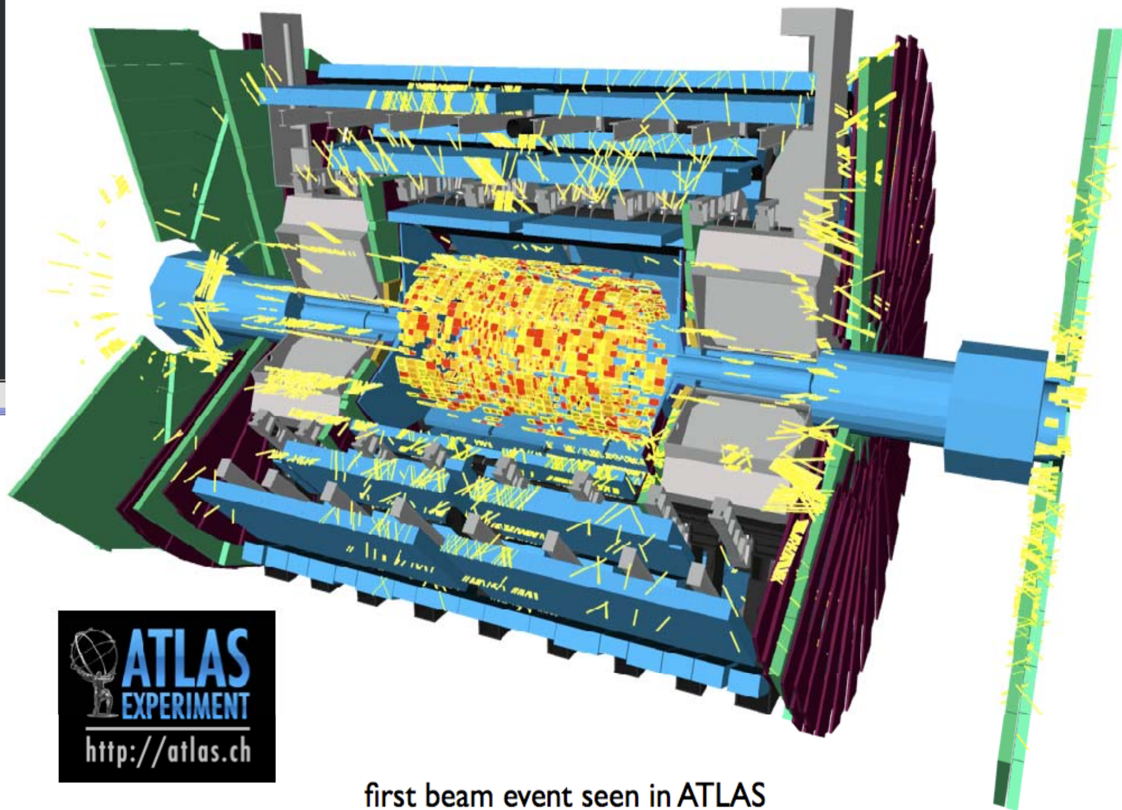




with cosmic rays.....



The very first beam-splash event from the LHC in ATLAS on 10th September 2008, 10:19

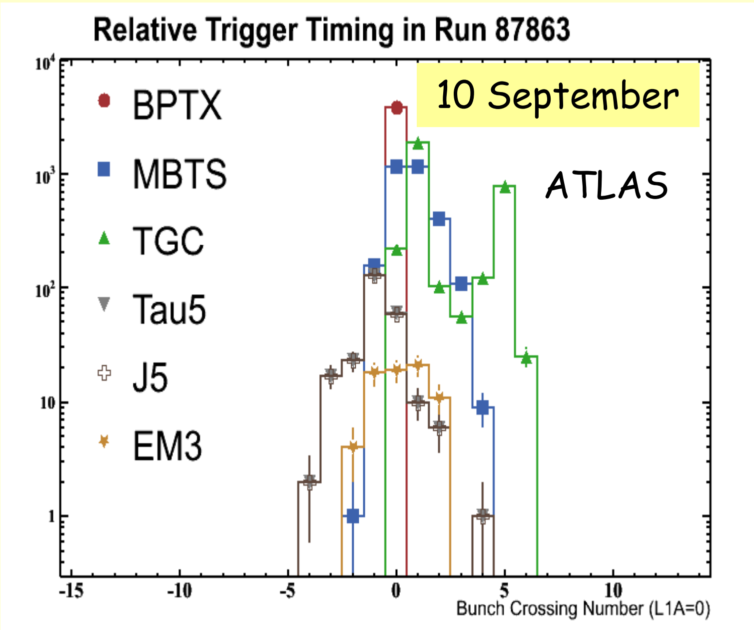


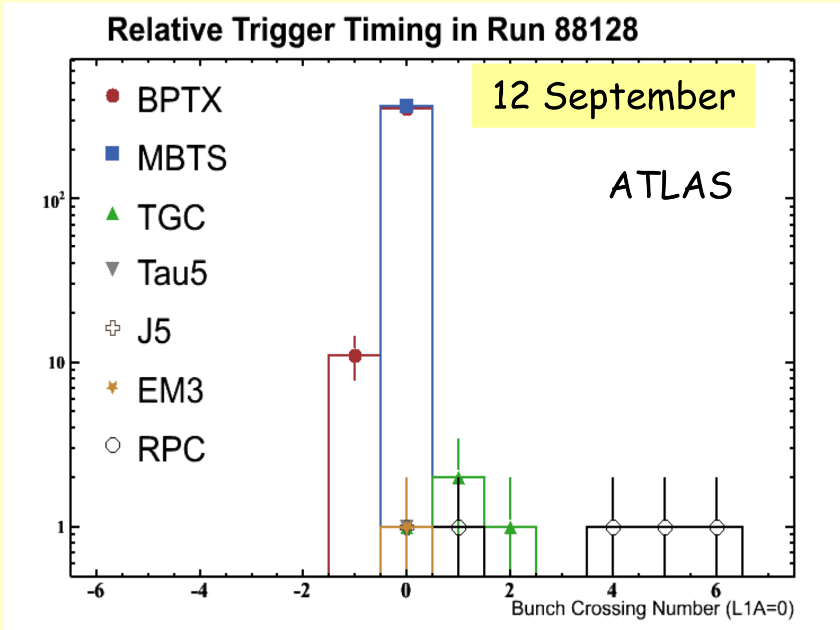
first beam event seen in ATLAS

....and beam related events

Trigger timing with beam splash events

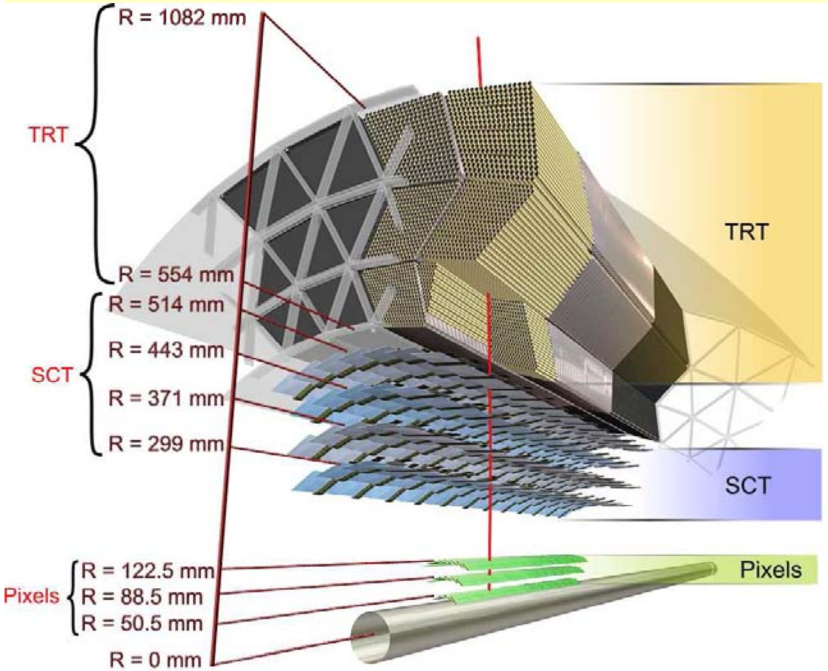
Few days of beam halo and splash events helped enormously to adjust timing of different triggers





1 bunch crossing number = 25 ns

The Inner Detector



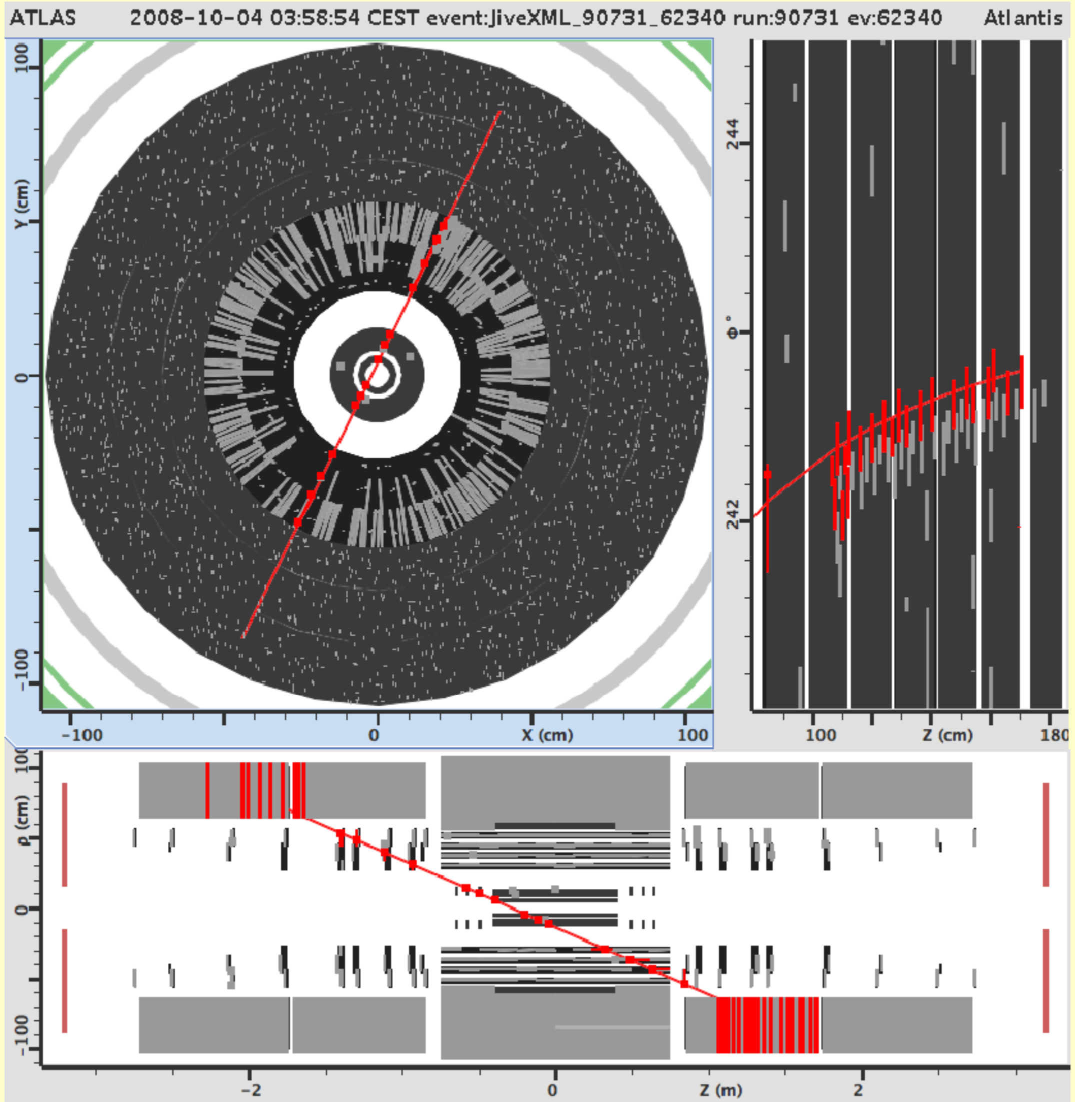
	R- ϕ accuracy	R or z accuracy	# channels
Pixel	10 μm	115 μm	80.4M
SCT	17 μm	580 μm	6.3M
TRT	130 μm		351k

$\sigma/p_T \sim 0.05\%\ p_T \oplus 1\%$

2008 Status and commissioning:

- The critical path issue was the evaporative cooling system repair and cleaning of the plant, after a failure on 1st May 2008, which ended late July
- Considerable running experience with the evaporative cooling system gained by now;
- 2.5% of channels lost due to cooling leaks and heater problems in endcaps (much can be recovered in shutdown)
- Meanwhile: significant data with all three subdetectors taken

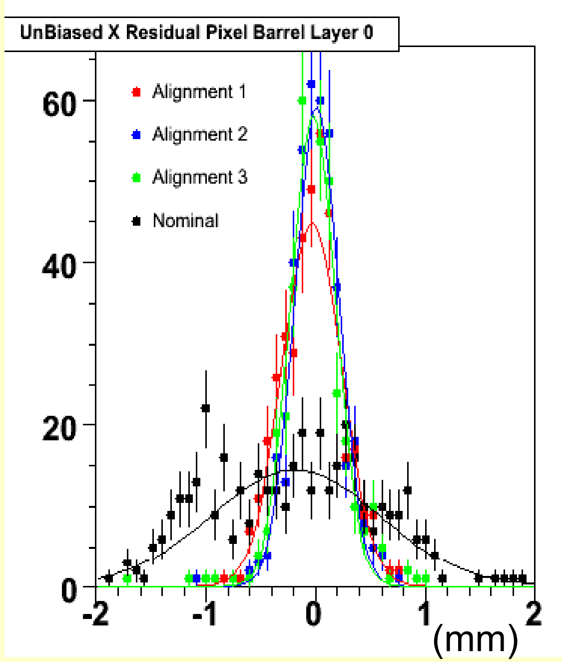
A combined barrel + endcap track



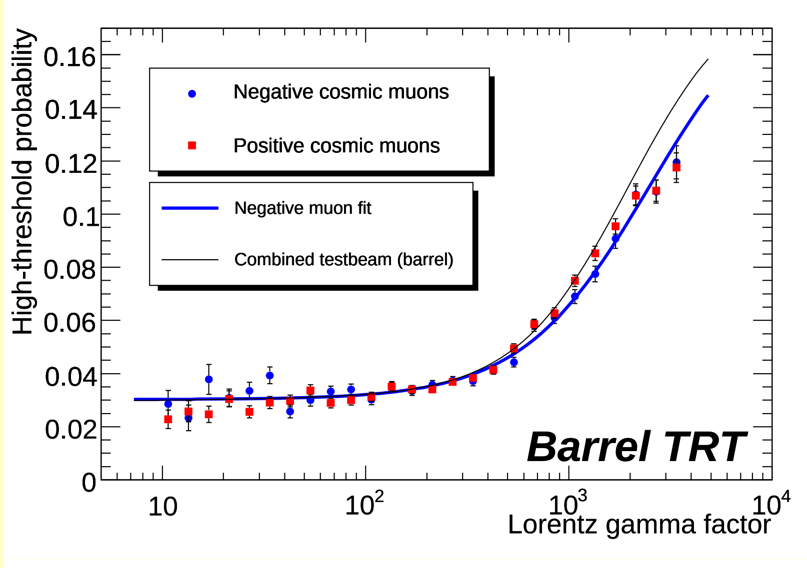
- Hits in:
  - TRT (endcap)
  - SCT (endcap and barrel)
  - Pixels (endcap and barrel)

- Very useful for alignment

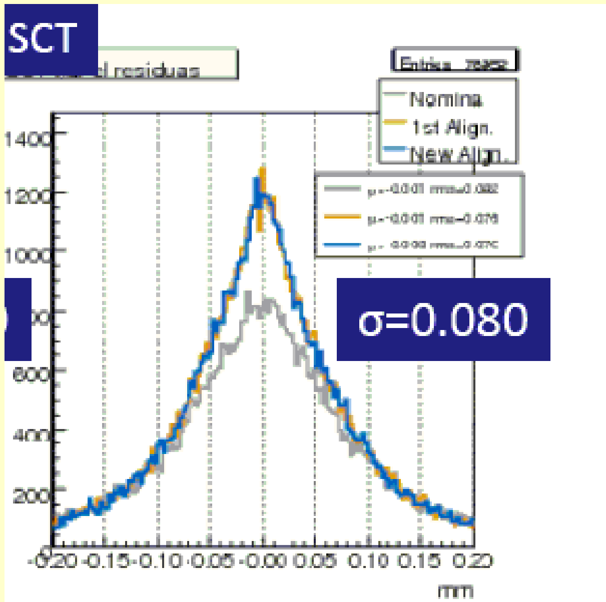
Inner Detector commissioning results



Mean x residuals of pixel barrel layer 0
(after various alignment steps)

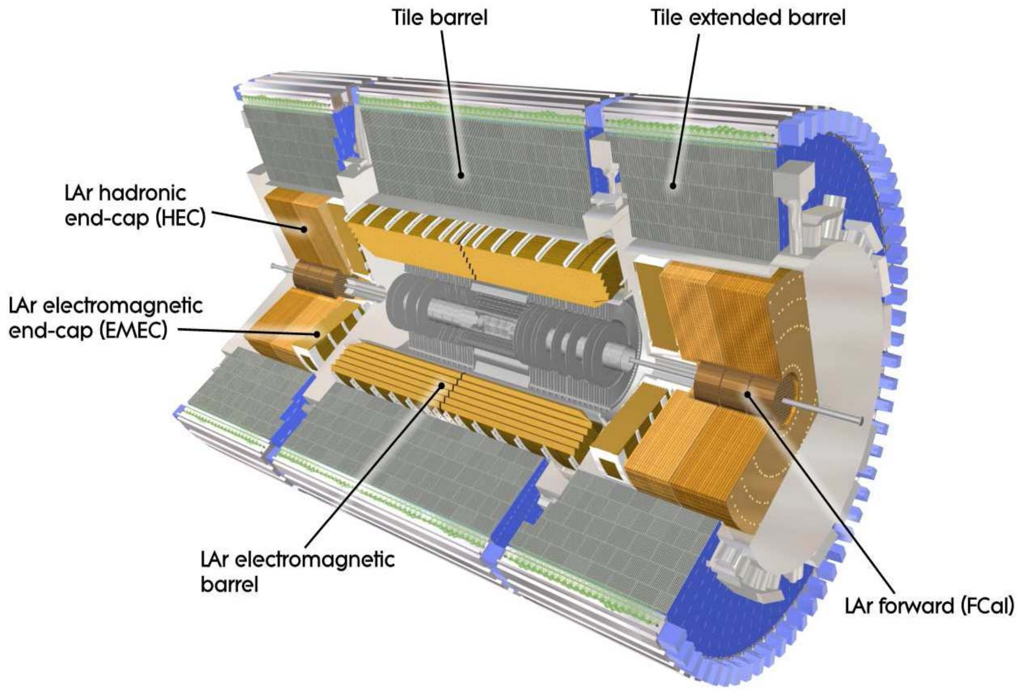


Turn-on of transition radiation produced from cosmic muons (Oct. 2008)



SCT residuals
(will improve with better alignment and calibration)

The Calorimeters



- Fine granularity in region of Inner Detector acceptance, $|\eta| < 2.5$:
  - $\sigma/E \sim 10\%/\sqrt{E} \oplus 0.7\%$
  - Linearity to ~0.1%
- Coarser granularity in the other regions sufficient for jet reconstruction and E_T^{miss} measurements
  - $\sigma/E \sim 50\% / \sqrt{E} \oplus 3\%$ (barrel / endcap)
  - $\sigma/E \sim 100\%/\sqrt{E} \oplus 10\%$ (forward)

Commissioning since ~3 years

- Good performance, small number of "dead channels":

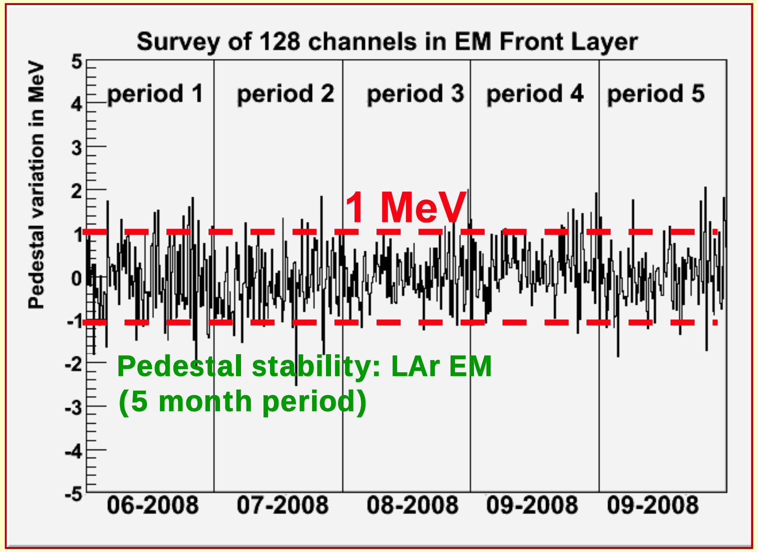
  - EM: ~0.01%
  - HEC: ~0.1%
    (+ Low voltage power supply problems, impacting ¼ of an endcap)
  - FCal: none
  - Tile Calorimeter: ~1.5%

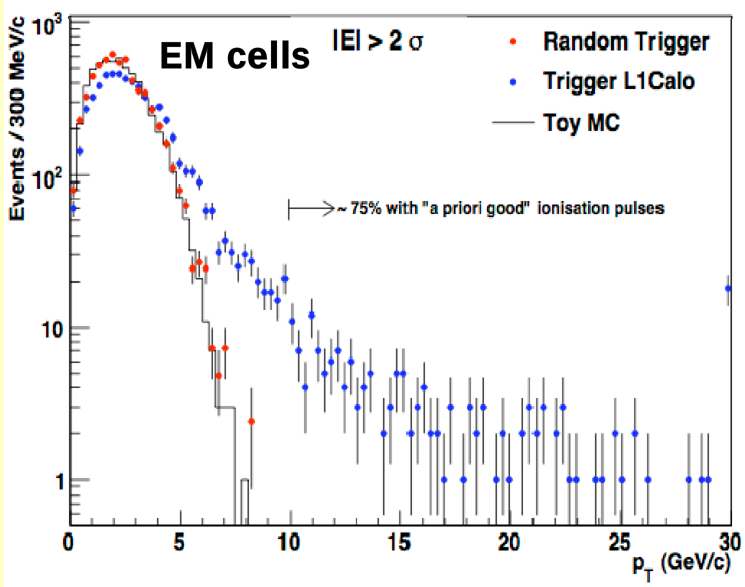
  Most of these can be recovered during the shutdown

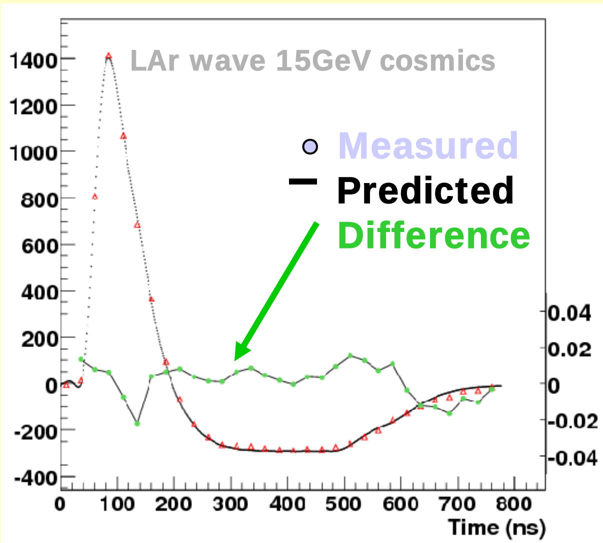
- Effort is now more focussed on:

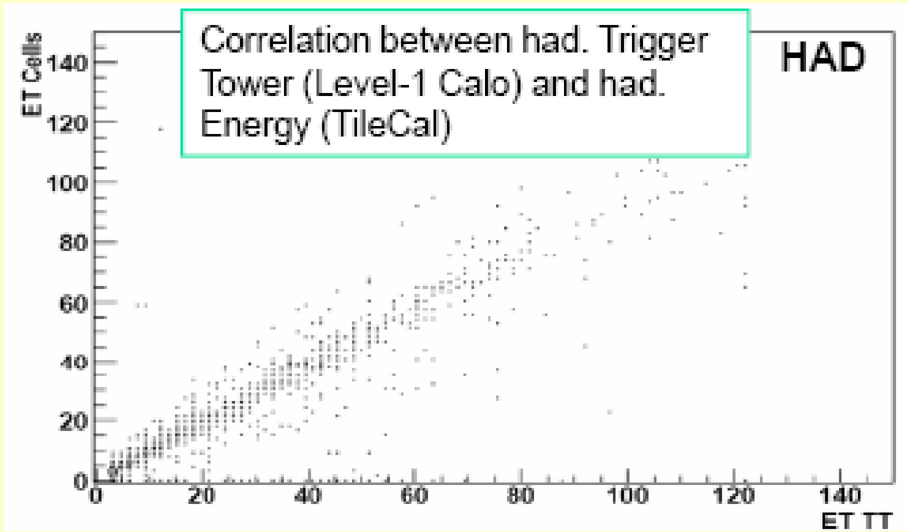
  * Long term stability
  * Prediction of the signal
  * Extraction of calibration constants

Calorimeter commissioning results



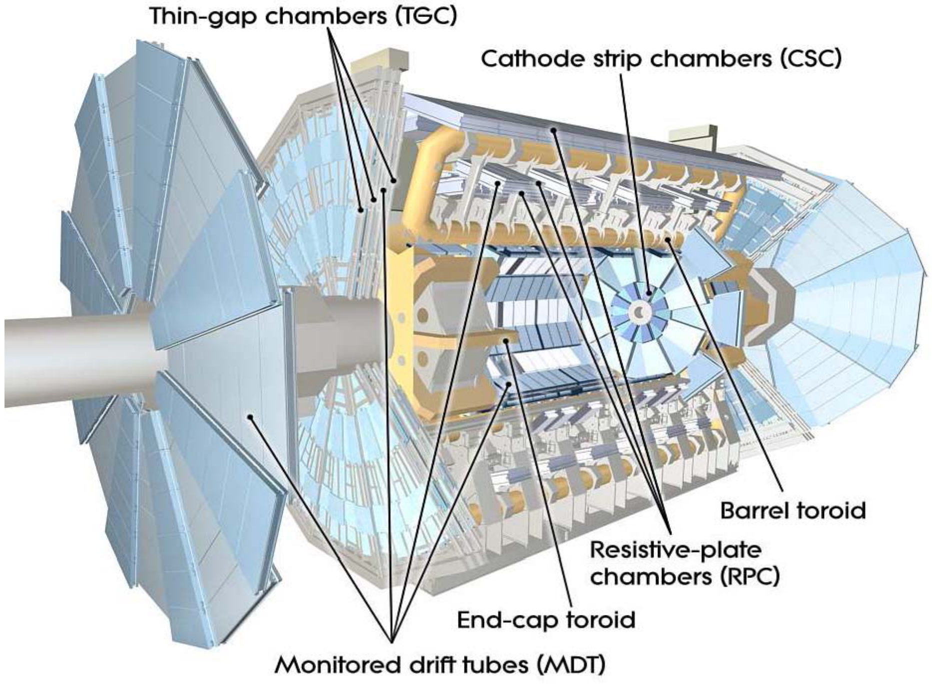






Precise knowledge is very important for an accurate calibration

The Muon Spectrometer



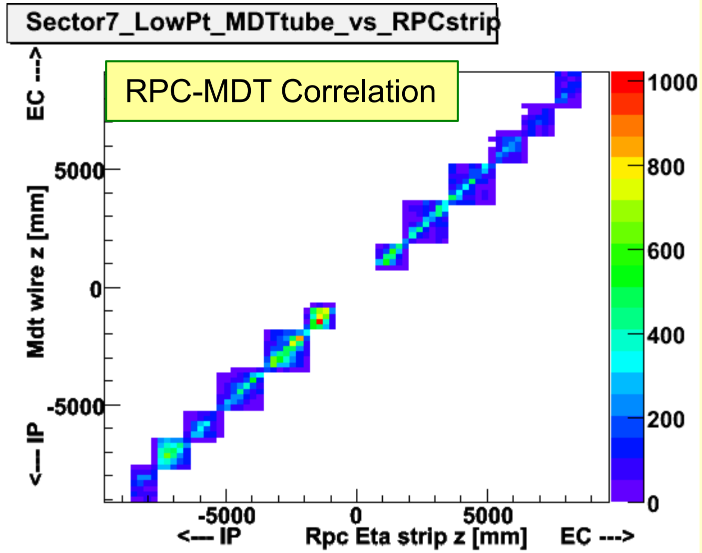
Chamber resolution	z/R	ϕ	time
MDT	35 μm	--	--
CSC	40 μm	5 mm	7 ns
RPC	10 mm	10 mm	1.5 ns
TGC	2-6 mm	3-7 mm	4 ns

Goal: 10% stand-alone muon resolution
for 1 TeV tracks

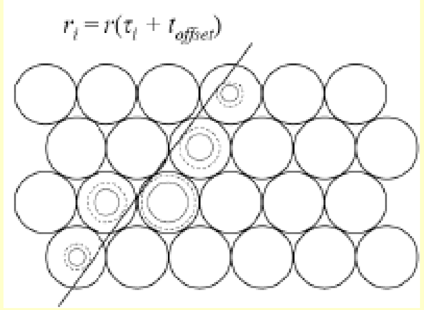
Status of commissioning:

- All chambers installed and used in global -cosmic and beam- running
  (for CSC: only short runs in combined mode acquired, still working on ROD debugging)
- Noise under control and low number of "dead channels"
  e.g. MDT: 1.5%, CSC: < 0.1%, TGC: 0.03%
  (recovery during shutdown possible)
- Excellent timing for RPC and TGC triggers achieved;
  Trigger system stable up to the nominal rate of 100 kHz in ATLAS (random triggers)
- Combined muon reconstruction achieved (muon system + Inner Tracker)

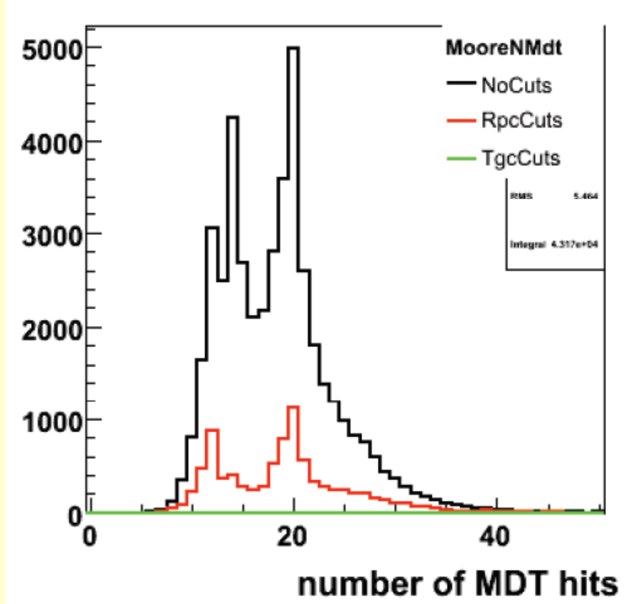
Muon spectrometer commissioning results



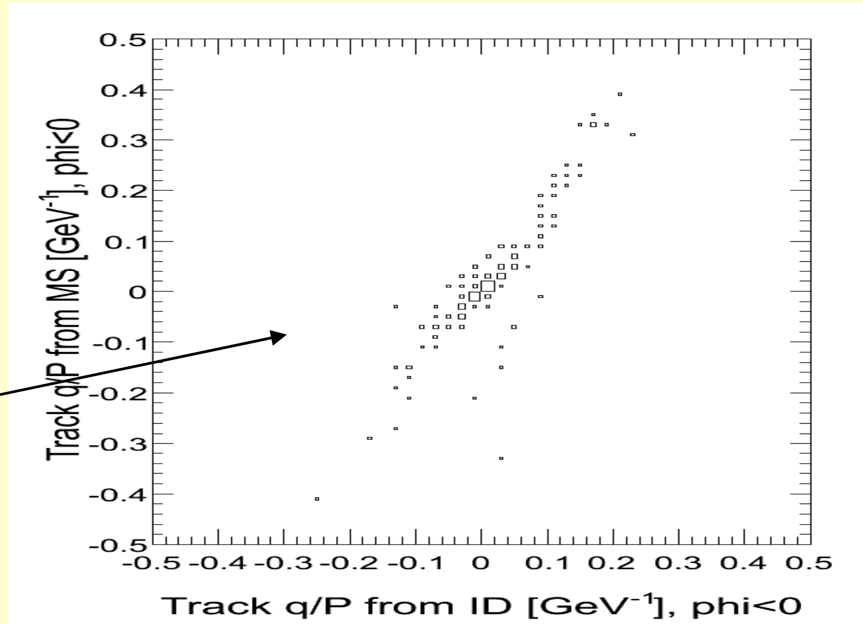
Good correlation between MDT and RPC



8 inner +
6 middle +
6 outer hits



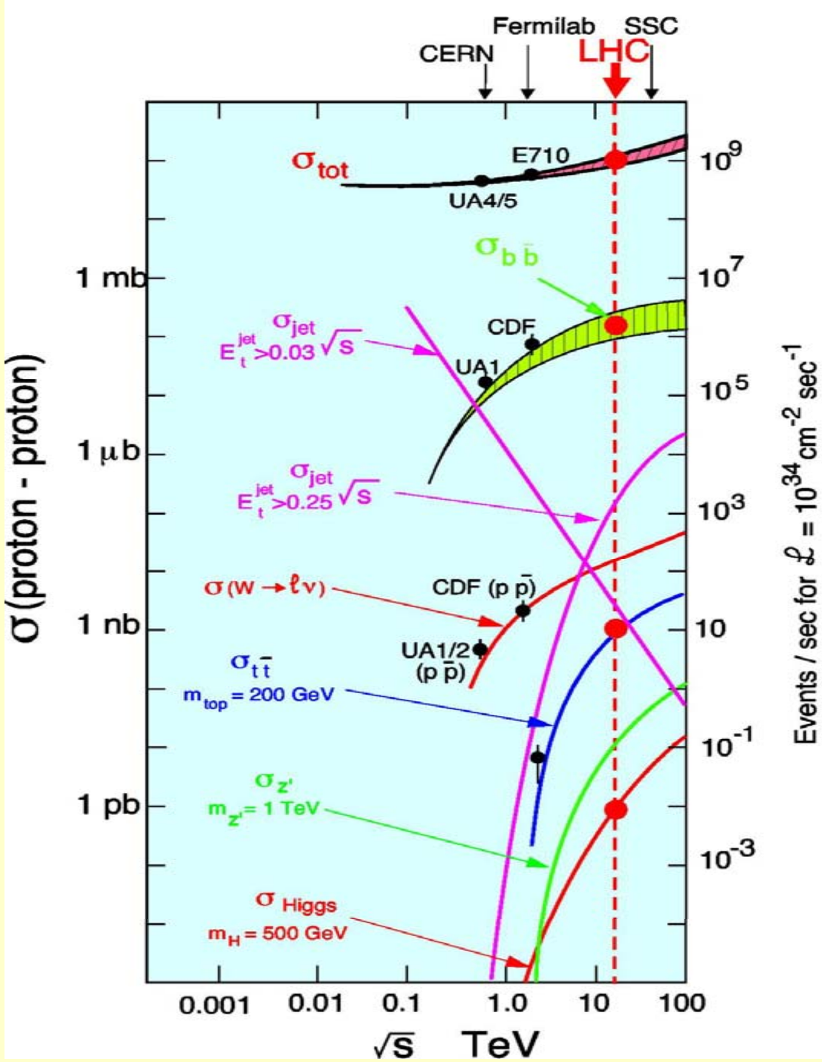
Correlation between the momentum measurement in the muon system and in the Inner detector



Towards First

Physics Results

Cross Sections and Production Rates, the first 10 pb^{-1}



Events for 10 pb^{-1}, $\sqrt{s}$ = 14 TeV

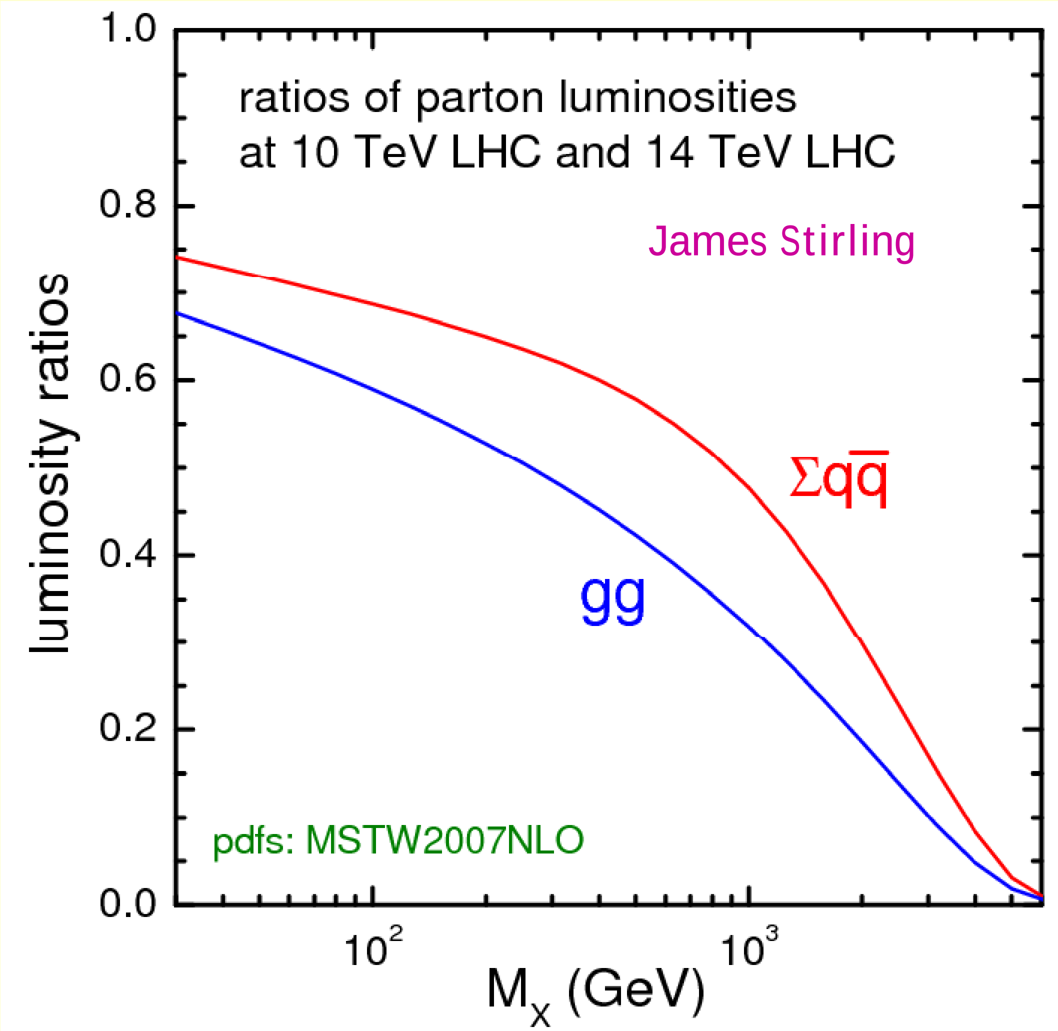
Inelastic pp (minimum bias events)	**large (prescaled)**
W → e ν **Z → ee**	**10^5** **10^4**
tt → eνb qqb	**10^3**
Higgs (130 GeV) **Gluinos (1 TeV)**	**10** **1**

<u>Physics with 10 – 100 pb^{-1}</u>:

- Establish Standard Model signals
- Use them for calibration
  (tag and probe methods,….)
- Tune Monte Carlos

- Basic SM cross section measurements
- Look for surprises
  (e.g. high mass di-lepton resonances,…
  ….., black holes)

10 vs 14 TeV ?



At 10 TeV, more difficult to create high mass objects...

Below about 200 GeV, this suppression is <50% (process dependent)

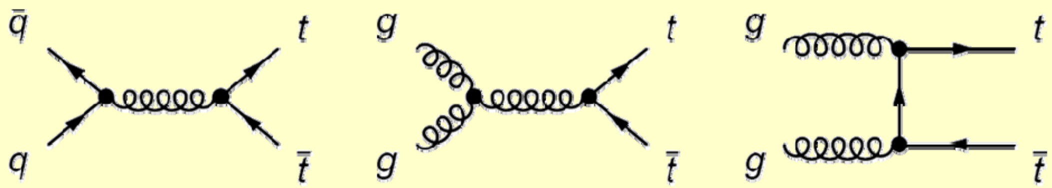
e.g. tt ~ factor 2 lower cross-section

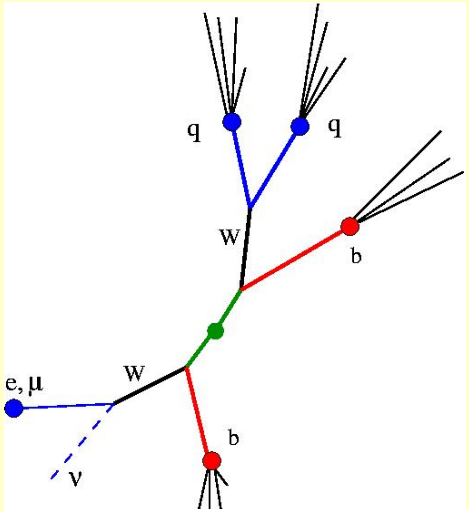
Above ~2-3 TeV the effect is more marked

The rest of the talk discusses √s=14 TeV capabilities

Top Quark Physics

at the LHC





1,2 or 0 lepton final states

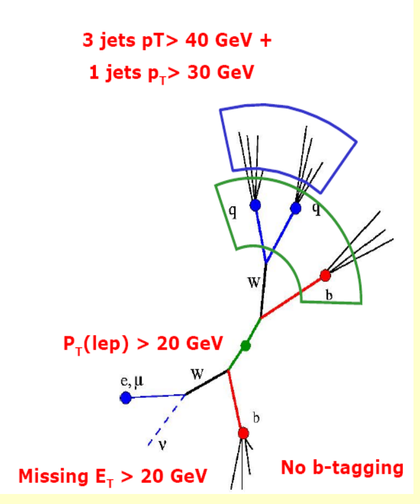
<u>Physics Motivation</u>:

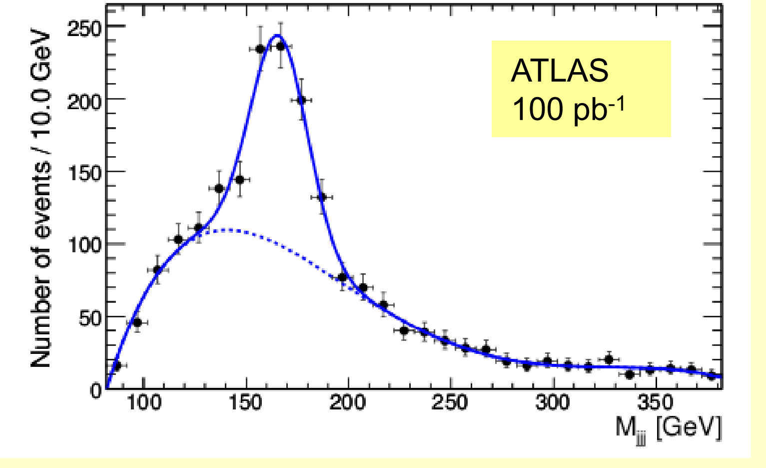
- Electroweak precision test via top quark mass
- Special role in el. weak symmetry breaking ?
  Yukawa coupling ~ 1
- Test of perturbative QCD, strong production
- Sensitive to new physics via rare decays

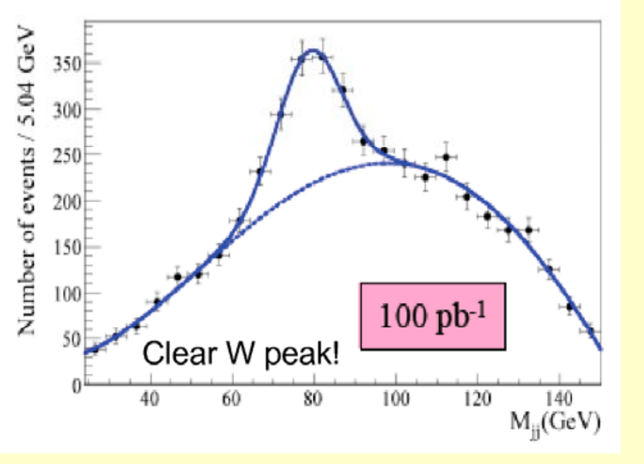
Early Physics: Top cross section without / with b-tagging

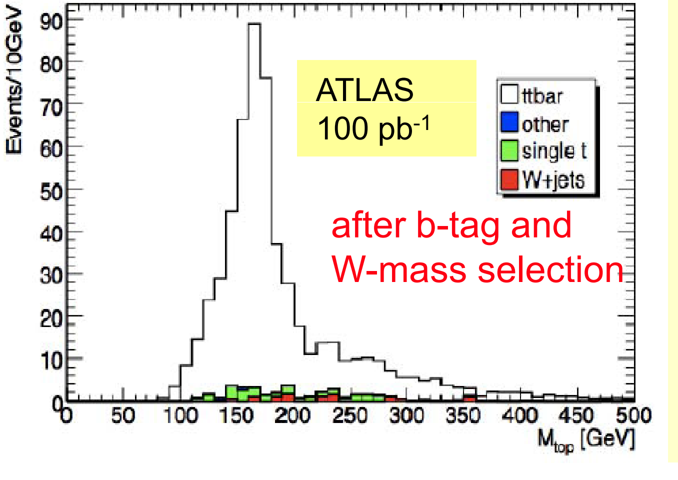
Large cross section: ~ 830 pb

Reconstructed mass distribution after a simple selection of **tt → Wb Wb → ℓνb qqb** decays:





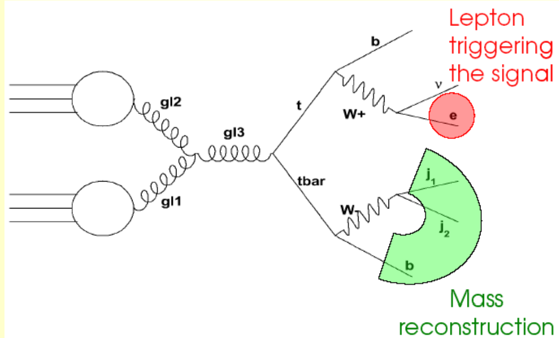




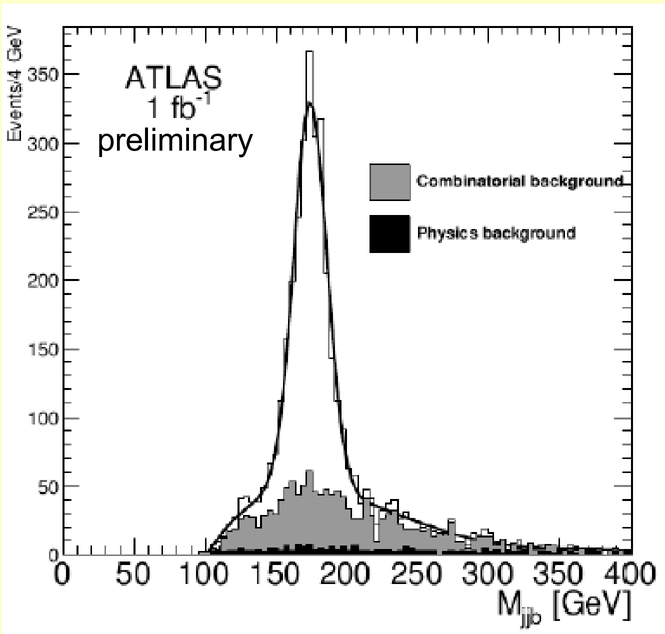
- Cross section measurement (test of perturbative QCD) with data corresponding to 100 pb^{-1} possible with an accuracy of ±10-15%
- Errors are dominated by systematics
  (jet energy scale, Monte Carlo modeling (ISR, FSR),….)
- Ultimate reach (100 fb^{-1}): ± 3-5%
  (limited by uncertainty on the luminosity)

Top Quark Mass

Analysis steps: (1-lepton channel, most promising)



- Event selection
- Reconstruction of hadronic W (e.g. χ^2 method,…)
- Reconstruction of hadronic top
  (several methods for b-quark assignment,
  e.g. use the one closest to the hadronic W)
- Likelihood fit of reconstructed top mass



Expected syst. uncertainties (1-lepton, 1 fb^{-1}):

Systematic uncertainties	χ^2 minimization method
Light Jet Energy Scale	0.2 GeV/%
b Jet Energy Scale	0.7 GeV/% ←
ISR/FSR	$\simeq$ 0.3 GeV
b quark fragmentation	$\leq$ 0.1 GeV
Background	negligible
Method	0.1 to 0.2 GeV

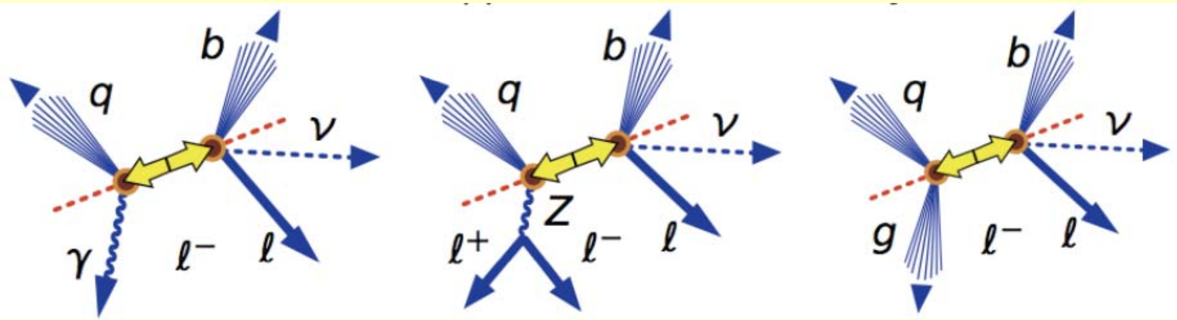
main syst. uncertainty: b-jet energy scale

Expected LHC precision, 10 fb^{-1}: $\Delta m_t <\ \sim 1$ GeV

From a combination of different methods with different systematics; might be conservative

Rare top decays

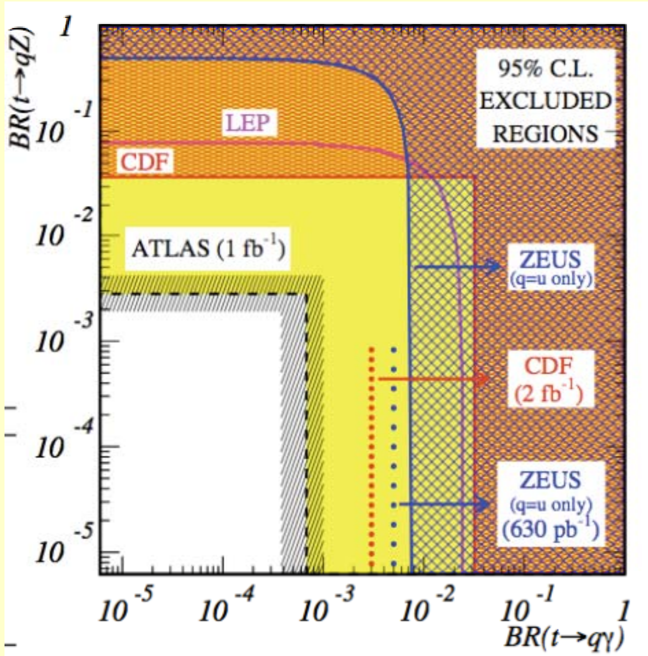
FCNC decays into $q\gamma$, qZ and qg



BR in Standard Model:
~ 10^{-12} for $q\gamma$ and qZ
~ 10^{-10} for qg

Process	Expected 95% C.L. sensitivity (1 fb^{-1})
$t \to q\,\gamma$	$6.8 \cdot 10^{-4}$
$t \to q\,Z$	$2.8 \cdot 10^{-3}$
$t \to q\,g$	$1.2 \cdot 10^{-2}$

Expected 5σ discovery sensitivity for 100 fb^{-1}:
for qg and qZ final states: ~ 10^{-4}



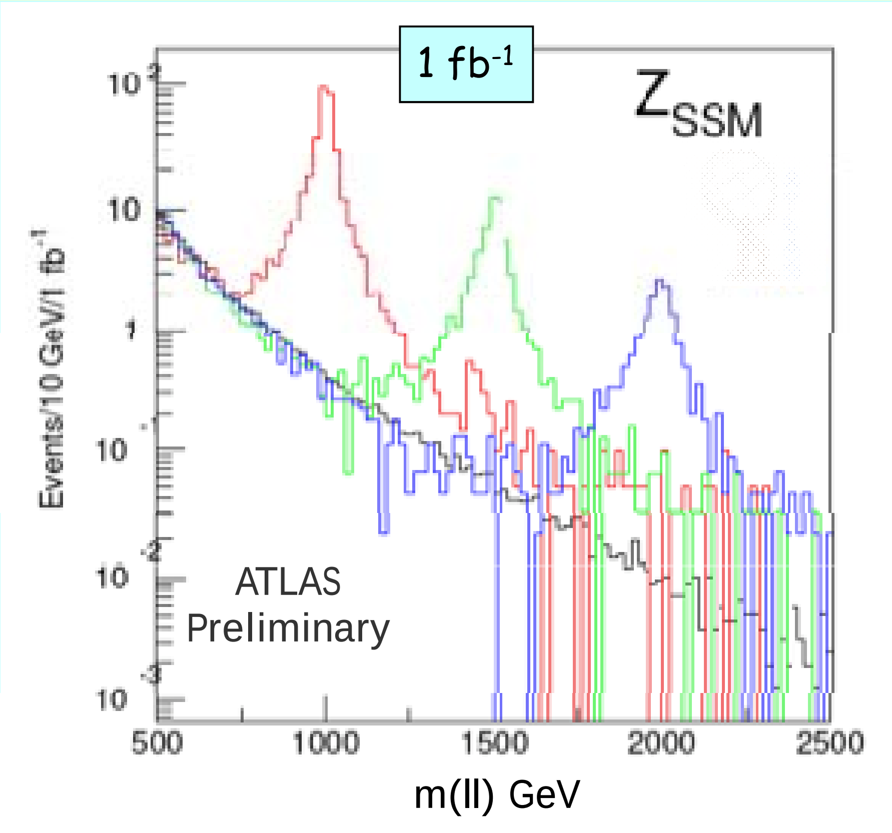
Early Surprises ??

- as already mentioned, the experiments must be open for surprises / unknowns / unexpected discoveries

- requires unbiased measurements of
  - inclusive lepton spectra
  - dilepton spectra……
  - ETmiss spectrum…….
  - ……

One example of many….

$Z' \rightarrow e^+e^-$ with SM-like couplings (Z_{SSM})



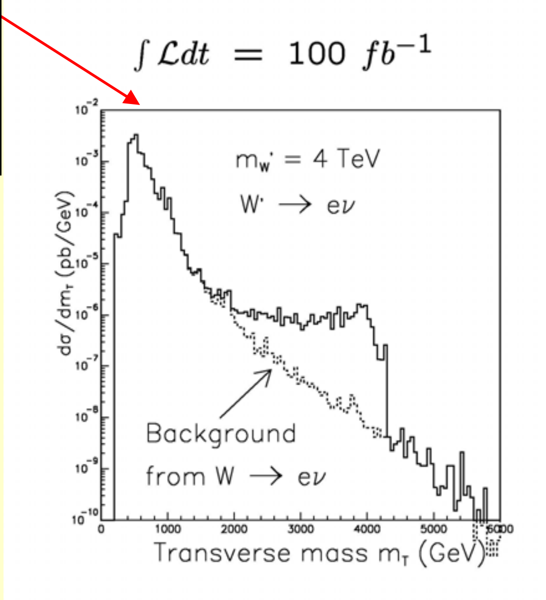
Mass (TeV)	Events / fb^{-1} (after cuts)	Luminosity needed for a 5σ discovery + (10 obs. events)
1	~160	~70 pb^{-1}
1.5	~30	~300 pb^{-1}
2	~7	~1.5 fb^{-1}

Discovery reach above Tevatron limits m ~ 1 TeV, perhaps in 2009... (?)

LHC reach for BSM Physics with higher luminosity

(a few examples for 30 and 100 fb^{-1})

	30 fb $^{-1}$	100 fb $^{-1}$
Excited Quarks $Q^* \to q\,\gamma$	M (q*) ~ 3.5 TeV	M (q*) ~ 6 TeV
Leptoquarks	M (LQ) ~ 1 TeV	M (LQ) ~ 1.5 TeV
$Z' \to \ell\ell$, jj $W' \to \ell\,\nu$	M (Z') ~ 3 TeV M (W') ~ 4 TeV	M (Z') ~ 5 TeV M (W') ~ 6 TeV
Compositeness (from Di-jet)	Λ ~ 25 TeV	Λ ~ 40 TeV



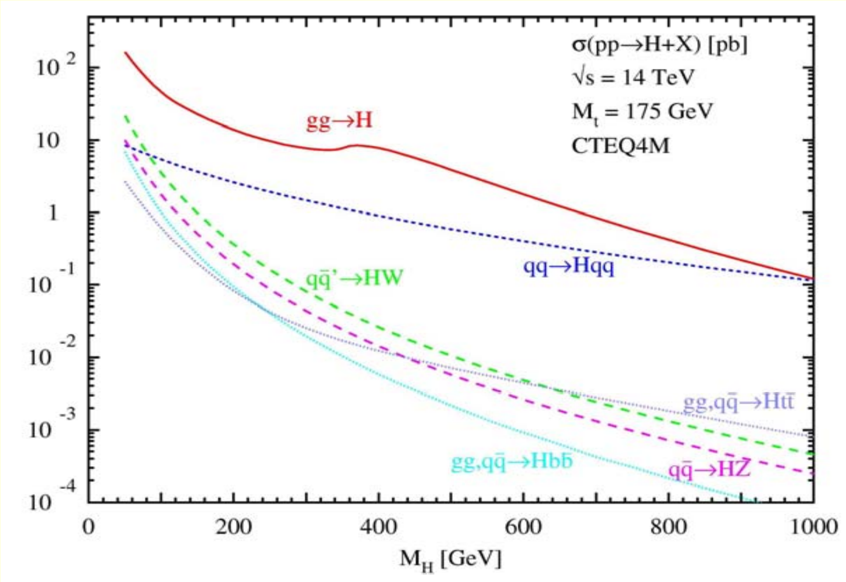
The Search for

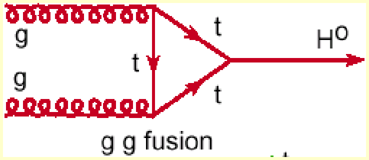
The Higgs boson

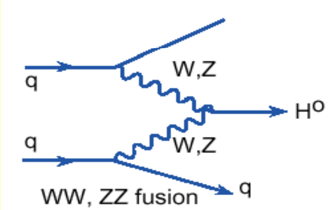
The first Higgs at ATLAS

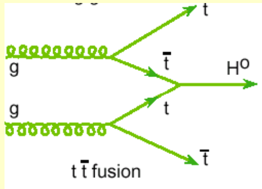
Standard Model
Higgs Boson Searches

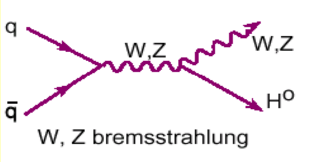
NLO cross sections, M.Spira et al.











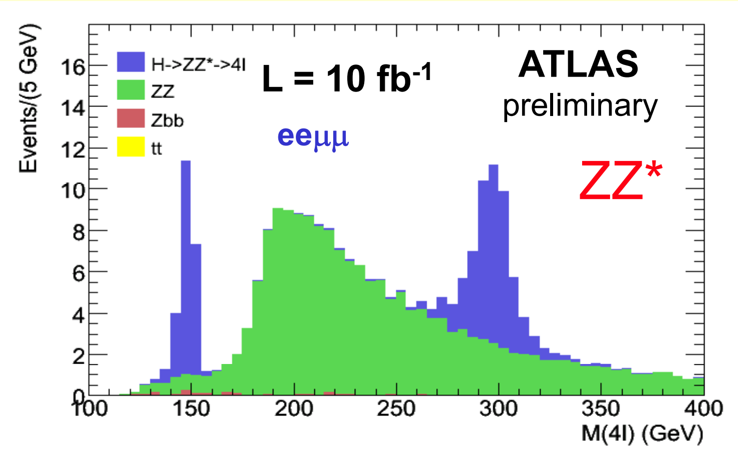
1. The high mass region, $m_H > 200$ GeV (easy, lepton modes or large E_T^{miss})
   $H \to ZZ \to \ell\ell\,\ell\ell$, $qq\nu\nu$ and $H \to WW \to \ell\nu\,\ell\nu$, $\ell\nu\, qq$

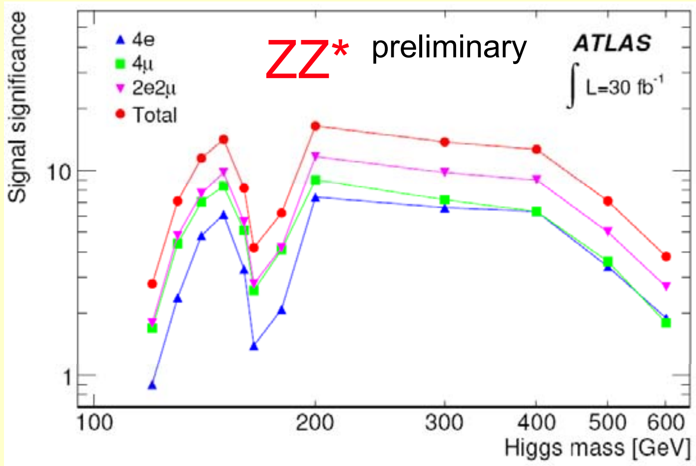
2. $m_H \sim 170$ GeV (fast discovery possible via WW decay modes)
   $H \to WW \to \ell\nu\,\ell\nu$ and $qqH \to qqWW \to qq\,\ell\nu\,\ell\nu$

3. Light Higgs, $m_H \sim 120$ GeV (most difficult case)
   $H \to \gamma\gamma$, $qqH \to qq\tau\tau$ and $ttH \to tt\, bb$ (?)

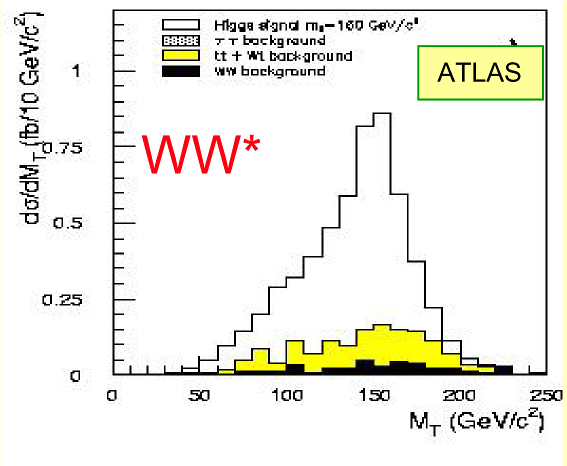
H → ZZ* → ℓℓ ℓℓ and H → WW → ℓν ℓν

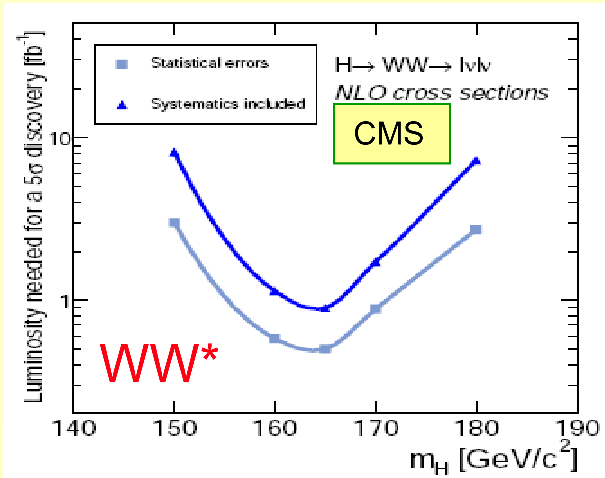
Updated ATLAS and CMS studies (NLO cross-sections, more realistic detector simulations), previous estimates confirmed





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

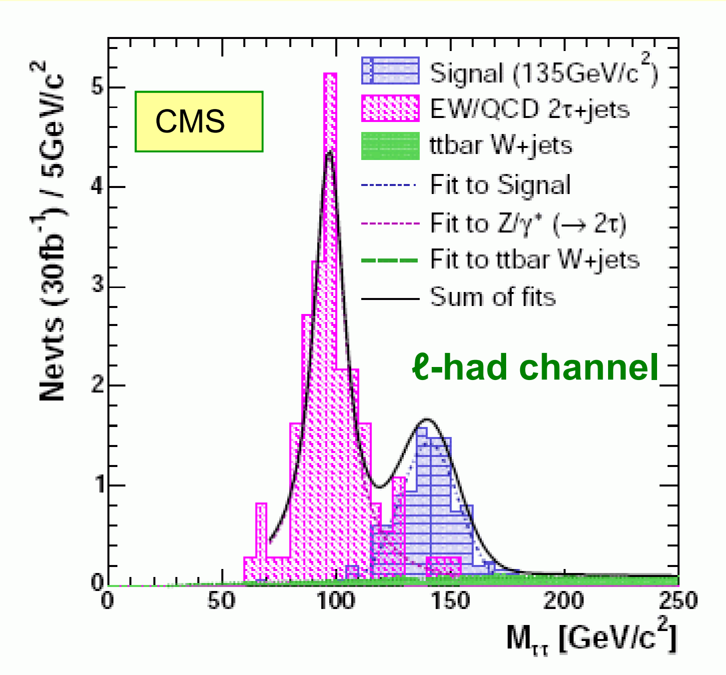




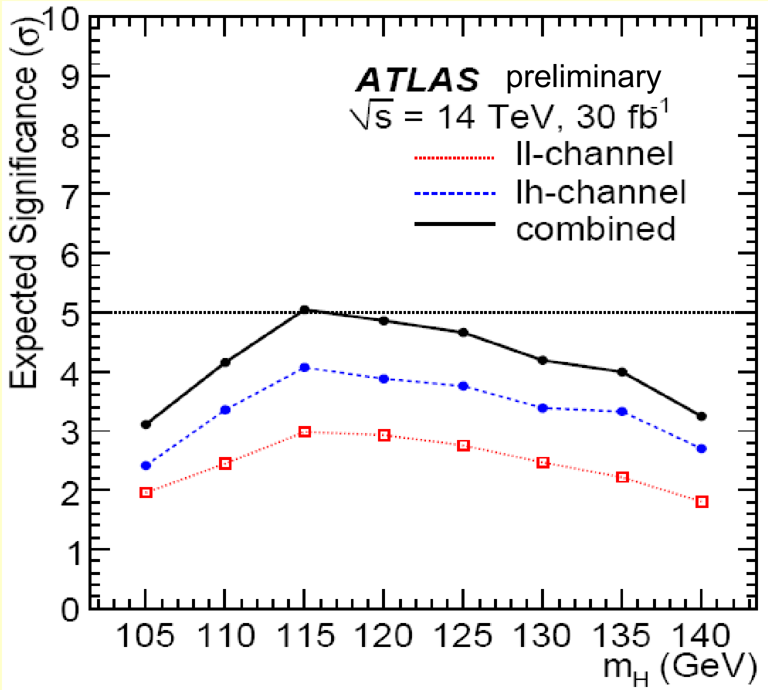
Discovery reach in H $\rightarrow$ ττ

Signal and background conditions in the vector boson fusion mode:

qq H $\rightarrow$ qq ττ $\rightarrow$ qq ℓνν had ν



ATLAS signal significance for 30 fb^{-1}

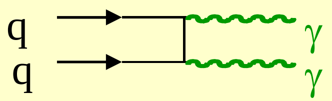


<u>Experimental challenge</u>:
- Identification of hadronic taus
- good E_T^{miss} resolution
  (ττ mass reconstruction in collinear approximation)
- control of the Z $\rightarrow$ ττ background shape
  in the high mass region

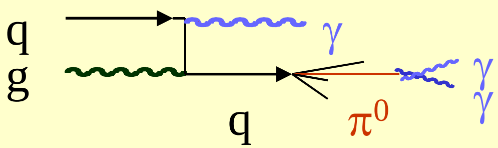
$H \to \gamma\gamma$

Main backgrounds:

$\gamma\gamma$ irreducible background



γ-jet and jet-jet (reducible)

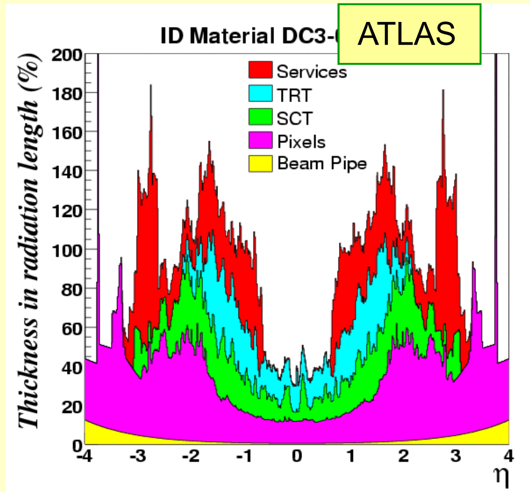


$\sigma_{\gamma j+jj} \sim 10^6\, \sigma_{\gamma\gamma}$ with large uncertainties

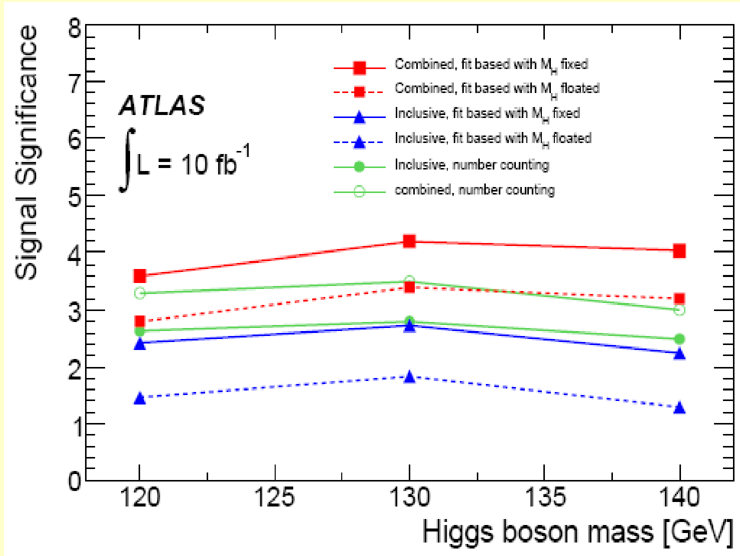
$\rightarrow$ need $R_j > 10^3$ for $\varepsilon_\gamma \approx 80\%$ to get

$\sigma_{\gamma j+jj} \ll \sigma_{\gamma\gamma}$

- Main exp. tools for background suppression:
  - photon identification
  - γ / jet separation (calorimeter + tracker)

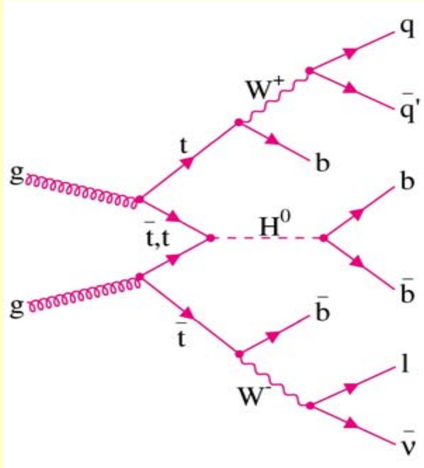


Note: also converted photons need to be reconstructed, large amount of material in the LHC trackers



- Comparable results for ATLAS and CMS
- Improvements possible by using more exclusive $\gamma\gamma$ + jet topologies

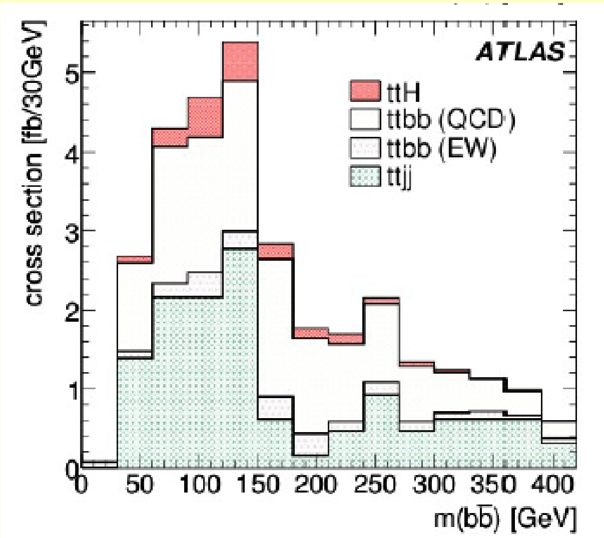
$t\bar{t}H \rightarrow t\bar{t}b\bar{b}$



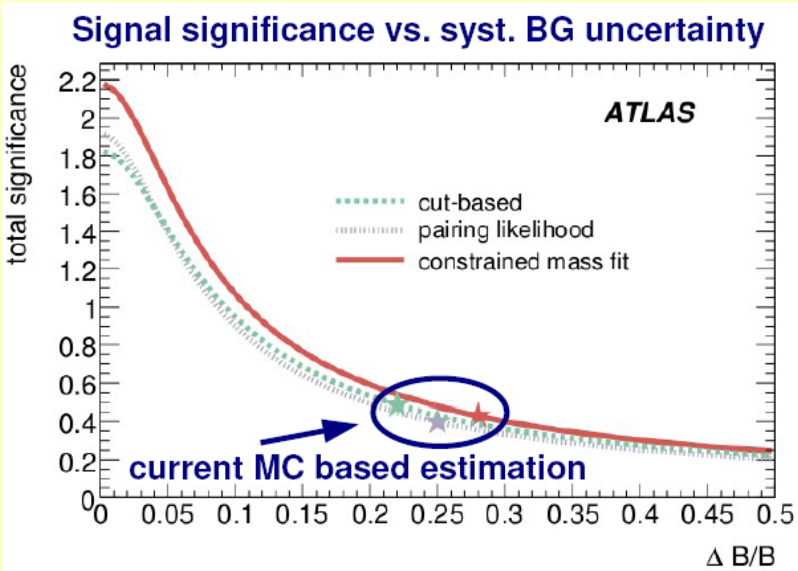
- Complex final states: $H \rightarrow bb$, $t \rightarrow bjj$, $t \rightarrow b\ell\nu$
  $t \rightarrow b\ell\nu$, $t \rightarrow b\ell\nu$
  $t \rightarrow bjj$, $t \rightarrow bjj$

- Main backgrounds:
  - combinatorial background from signal (4b in final state)
  - ttjj, ttbb, ttZ,…
  - Wjjjjj, WWbbjj, etc. (excellent b-tag performance required)

- Updated ATLAS and CMS studies: matrix element calculations for backgrounds
  → larger backgrounds (ttjj and ttbb)

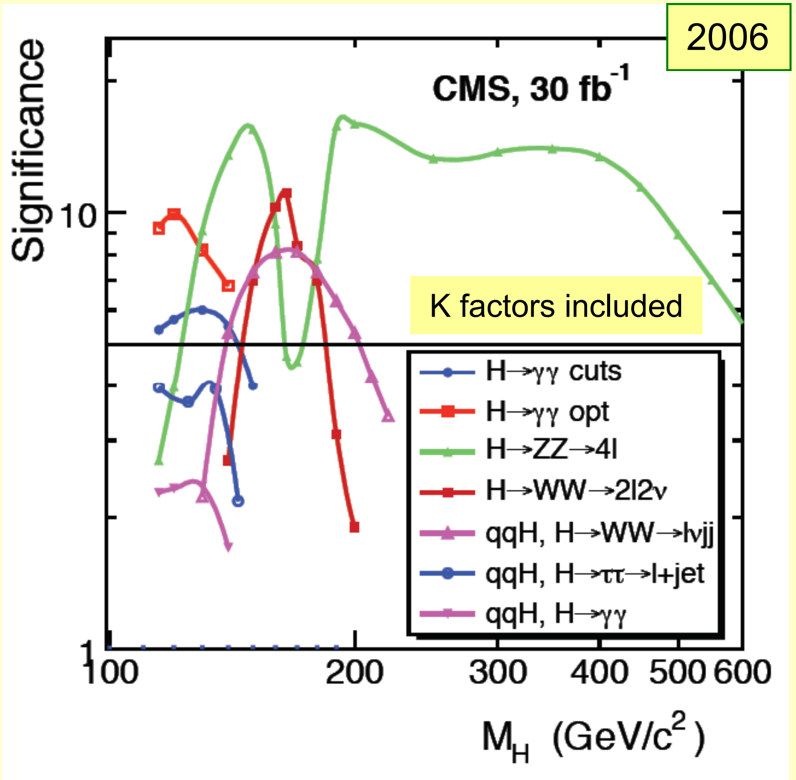


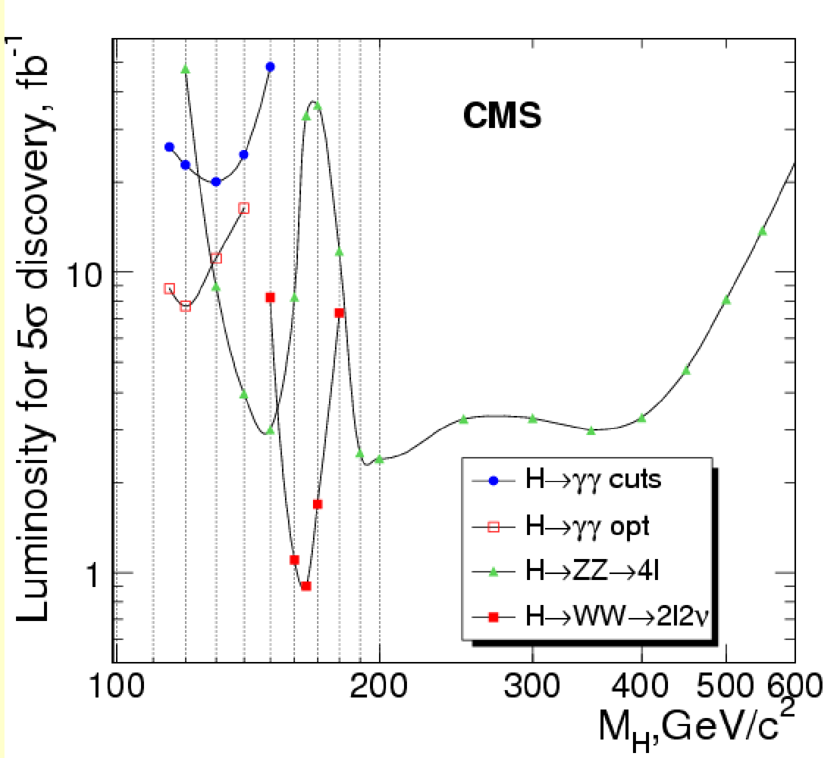
M (bb) after final cuts, 30 fb^{-1}



estimated uncertainty on the background: ± 25% (theory, + exp (b-tagging))
⇒ Normalization from data needed to reduce this (non trivial,…)

LHC discovery potential for 30 fb^{-1}

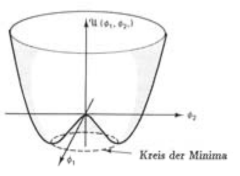




- Full mass range (up to ~ 1TeV) can be covered after a few years at low luminosity
  [at high mass: more channels (in WW and ZZ decay modes) available than shown here]
- Comparable performance in the two experiments
- Combining the two experiments, a 95% C.L. exclusion limit can be set with only 0.4 fb^{-1} over most of the mass range (~130 – 600 GeV)

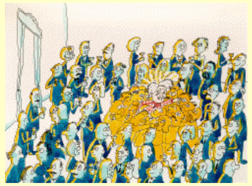
Important changes w.r.t. previous studies:

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



Is it a Higgs Boson ?

-can the LHC measure its parameters ?-



1. Mass

Higgs boson mass can be measured with a precision of 0.1%
over a large mass range (130 - ~450 GeV)
($\gamma\gamma$ and ZZ$\rightarrow 4\ell$ resonances, el.magn. calo. scale uncertainty assumed to be ± 0.1%)

2. Couplings to bosons and fermions

Relative couplings (Z/W, τ/W, t/W) can be measured with a precision of ~20%
(for 300 fb^{-1})

3. Spin and CP

Angular distributions in the decay channel $H \rightarrow ZZ^{(*)} \rightarrow 4\ell$ are sensitive to spin and CP eigenvalue

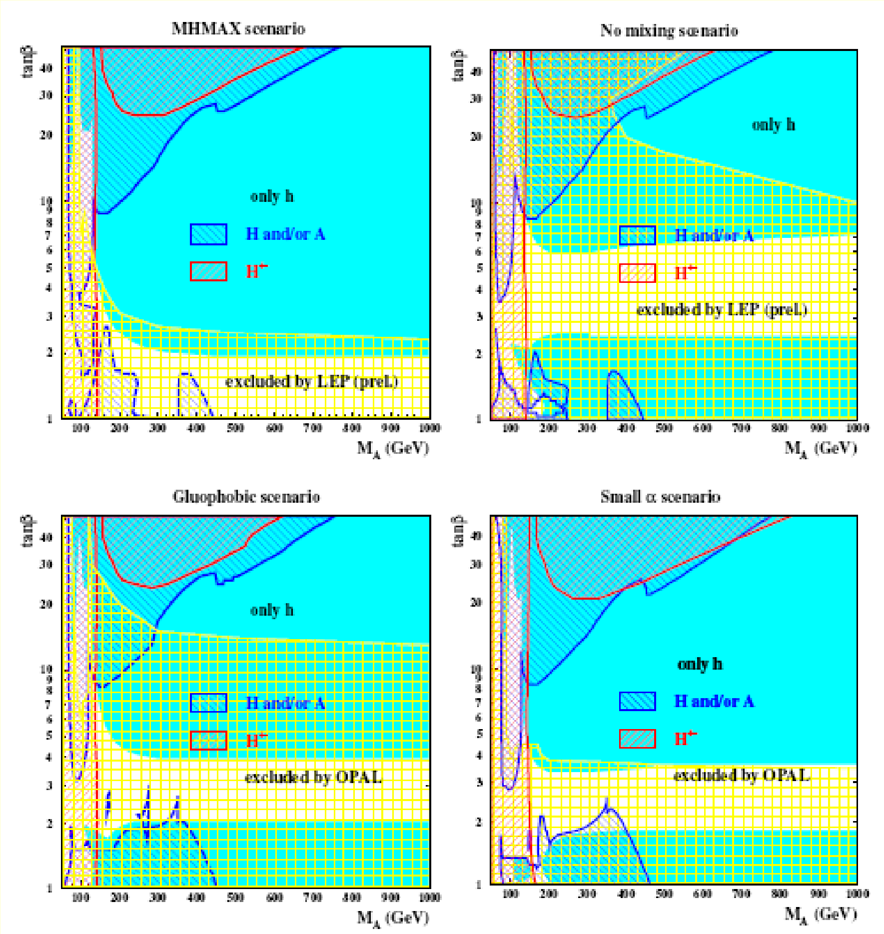
4. Higgs self coupling

Possible channel: **$gg \rightarrow HH \rightarrow WW\,WW \rightarrow \ell\nu\,jj\ \ell\nu\,jj$** (like sign leptons)
Small signal cross-sections, large backgrounds from tt, WW, WZ, WWW, tttt, Wtt,...
$\Rightarrow$ no significant measurement possible at the LHC;
very difficult at a possible SLHC (6000 fb^{-1}), limited to mass region around 160 GeV

Updated MSSM scan for different benchmark scenarios

Benchmark scenarios as defined by M.Carena et al. (h mainly affected)

ATLAS preliminary,   30 fb^{-1},   5σ discovery



MHMAX scenario (M_{SUSY} = 1 TeV/c^2)
maximal theoretically allowed region for m_h

Nomixing scenario (M_{SUSY} = 2 TeV/c^2)
(1TeV almost excl. by LEP)
small m_h → difficult for LHC

Gluophobic scenario (M_{SUSY} = 350 GeV/c^2)
coupling to gluons suppressed
(cancellation of top + stop loops)
small rate for g g → H, H→ $\gamma\gamma$ and Z→4 ℓ

Small α scenario (M_{SUSY} = 800 GeV/c^2)
coupling to b (and **t**) suppressed
(cancellation of sbottom, gluino loops) for
large tan β and M_A 100 to 500 GeV/c^2

The full parameter space is covered for all scenarios

Summary / Conclusions

- After more than 15 years of hard work The *Large Hadron Collider* and the experiments will start data taking next year…
  ….. and Particle Physics will enter a new era

- The ATLAS experiment is well prepared to record the first data and extract the physics

- Interesting physics already expected in 2009/2010

- On the longer term: questions on the existence of
  - Higgs particles,
  - low energy supersymmetry (see next talk) or
  - many other phenomena beyond the Standard Model at the TeV scale

  can be answered.

  The answers will hopefully give guidance to theory …
  …. and future experiments