The Higgs Discovery Potential of ATLAS

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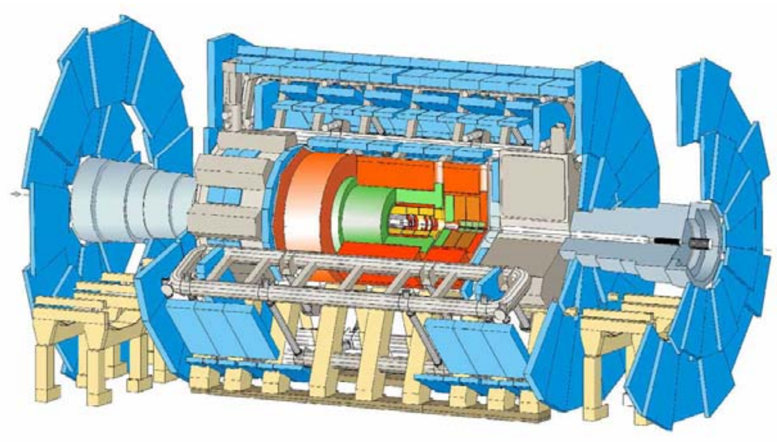
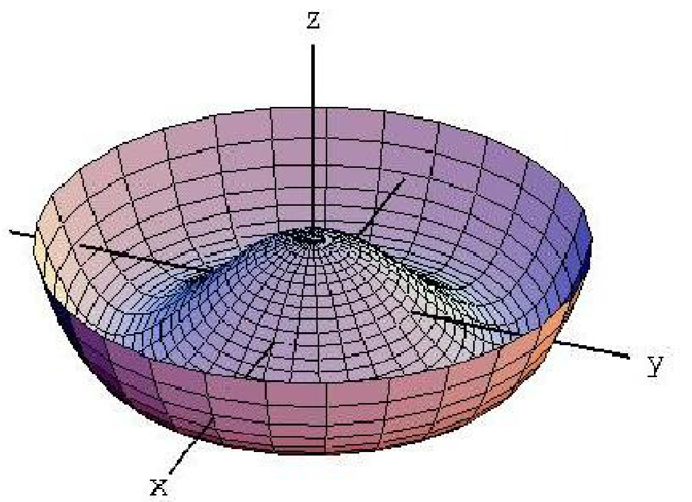
for the ATLAS Collaboration

http://atlas.ch

UNIVERSITY of GLASGOW



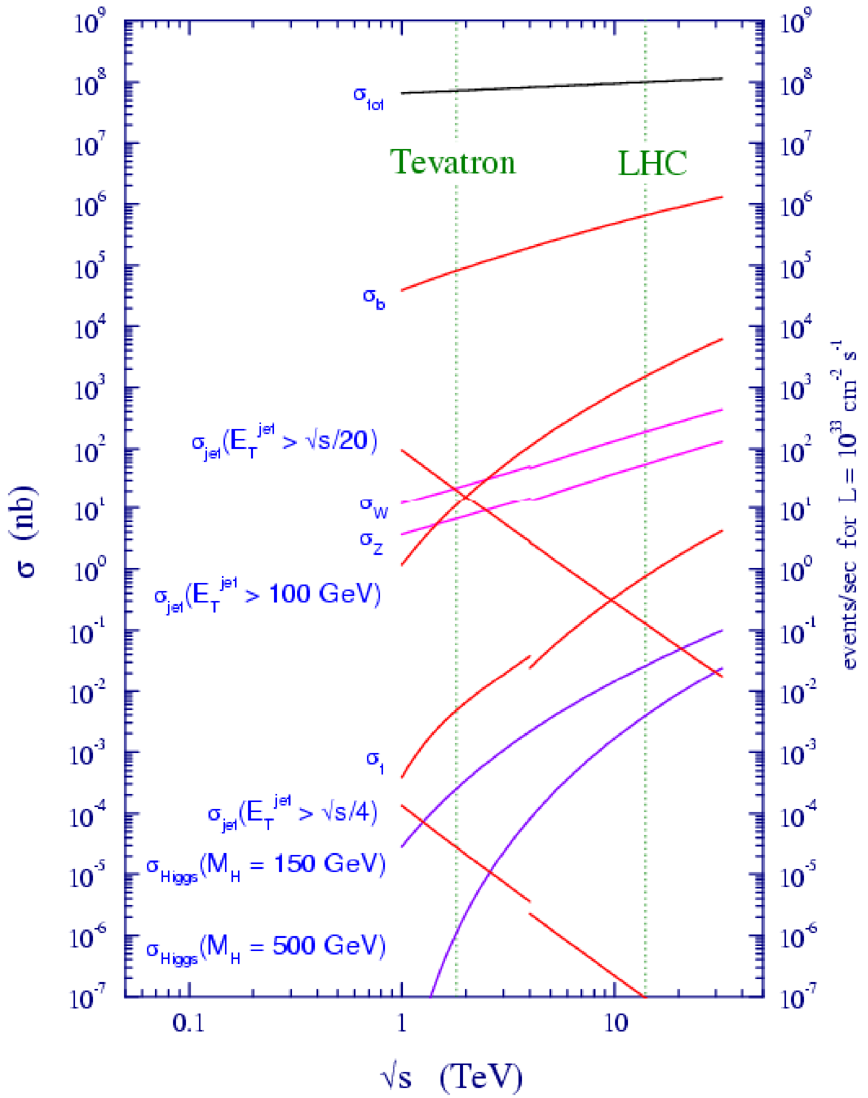


Outline

- LHC running conditions, event rates
- SM Higgs production & decay at the LHC
- The ATLAS detector
- Latest from Tevatron
- ATLAS SM Higgs sensitivity, and a selection of channels
- Basic MSSM scenarios
  - Only CP conserving considered here
- Conclusions

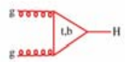
Running Conditions & Event Rates

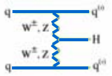
- First pp collisions expected from Summer 2008, $\sqrt{s}$=14 TeV.
- Luminosity scenarios:
  - For 2008: (initial running)
    - L < 10^{33} cm^{-2} s^{-1}, ∫Ldt ~ 1 fb^{-1}
  - For 2009: (low-luminosity phase)
    - L = 1-2 10^{33} cm^{-2} s^{-1}, ∫Ldt < 10 fb^{-1},
    - 30 fb^{-1} between 2008 and 2010/2011
  - Beyond: (high-luminosity phase)
    - L~10^{34} $cm^{-2}s^{-1}$,
    - ~300 fb^{-1} by 2014/2015
- Pile-up:
  - ATLAS expects ~2 (low-lumi) or 20 (high-lumi) p-p minimum bias interactions per bunch crossing (25 ns)



LHC SM Higgs Production

- Production processes , K-factors and cross-section uncertainties:


gluon fusion gg ⇒H — K~2.0, σ uncert ~10-20% NNLO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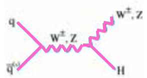
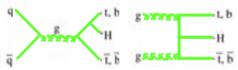

Z,W assoc. qq ⇒ HZ,W — K~1.4, σ uncert ~5% NNLO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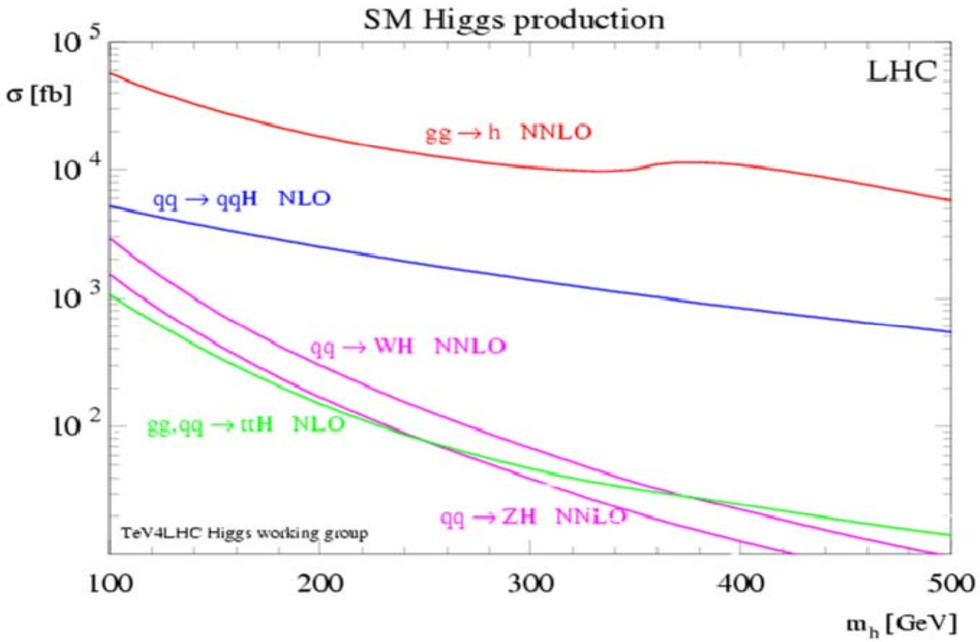

LHC SM Higgs Production and Decay

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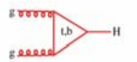

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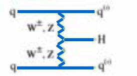

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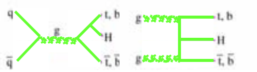

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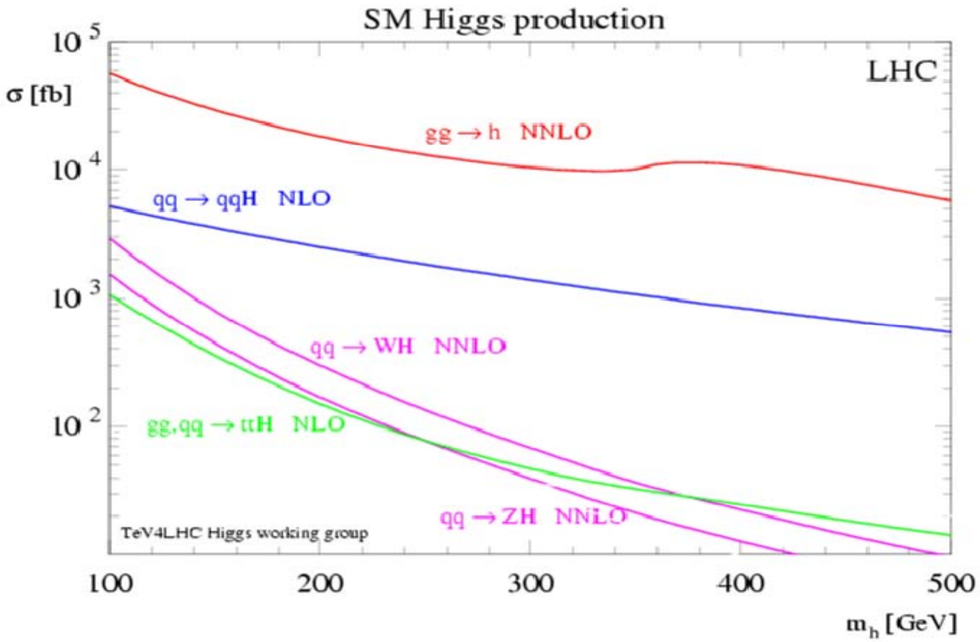

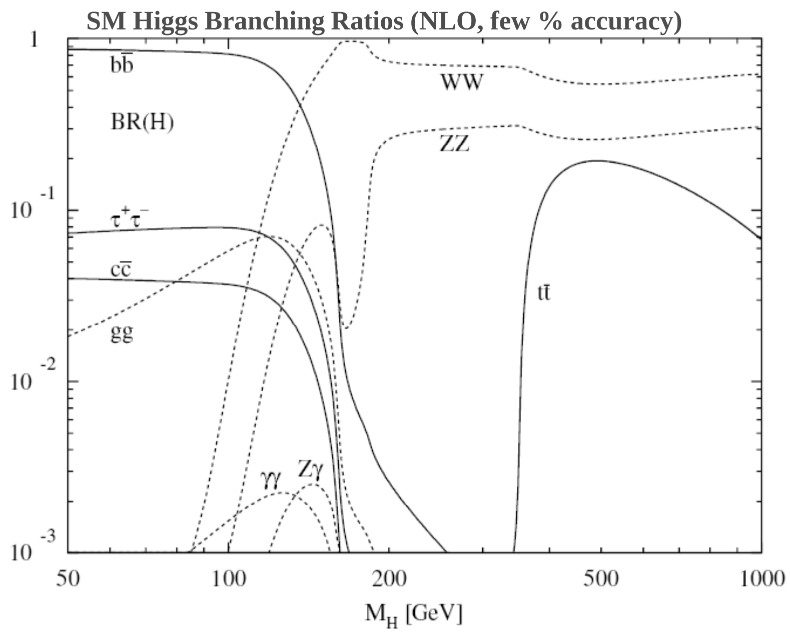

ZZ

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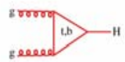

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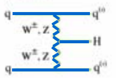

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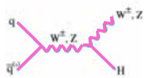

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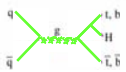


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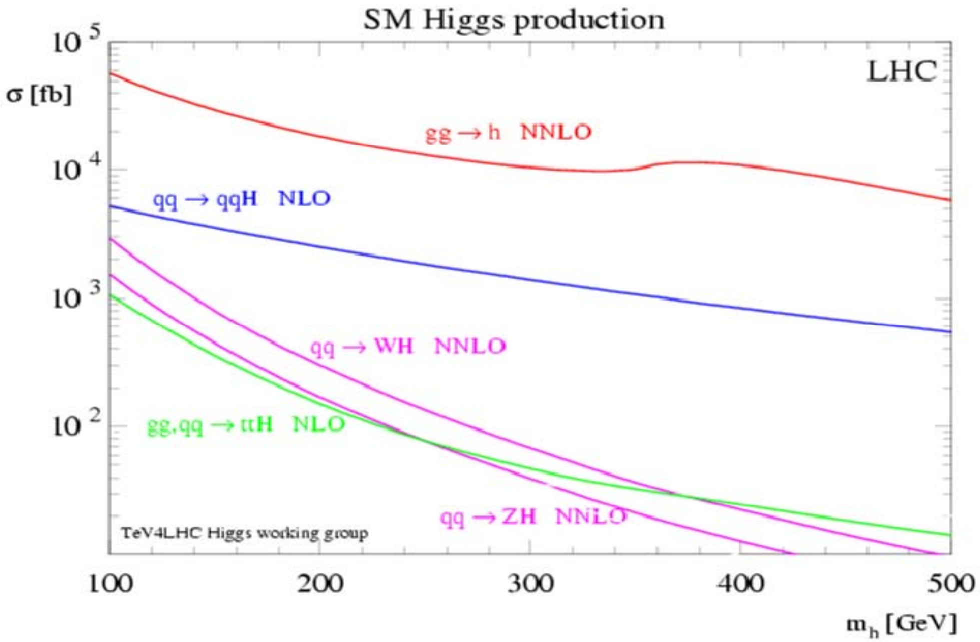

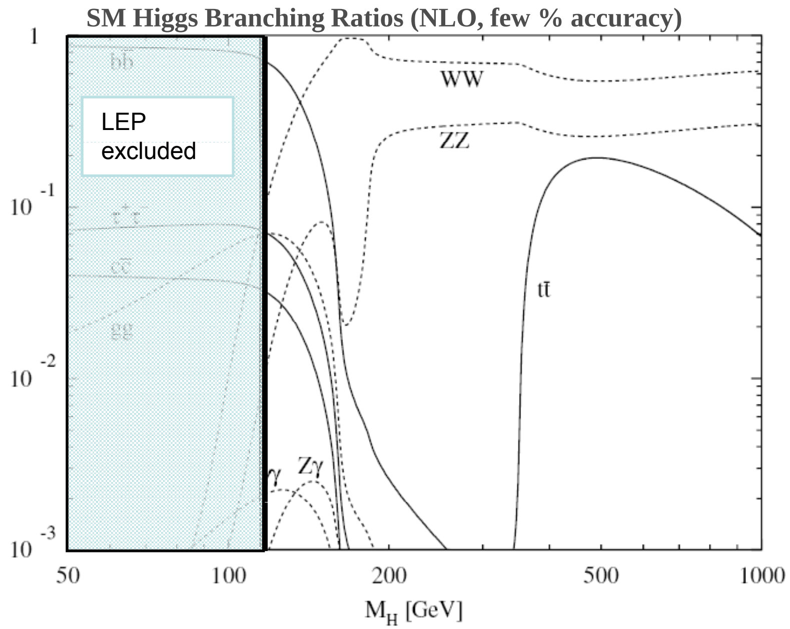

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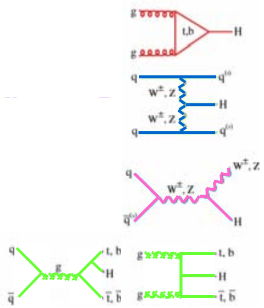

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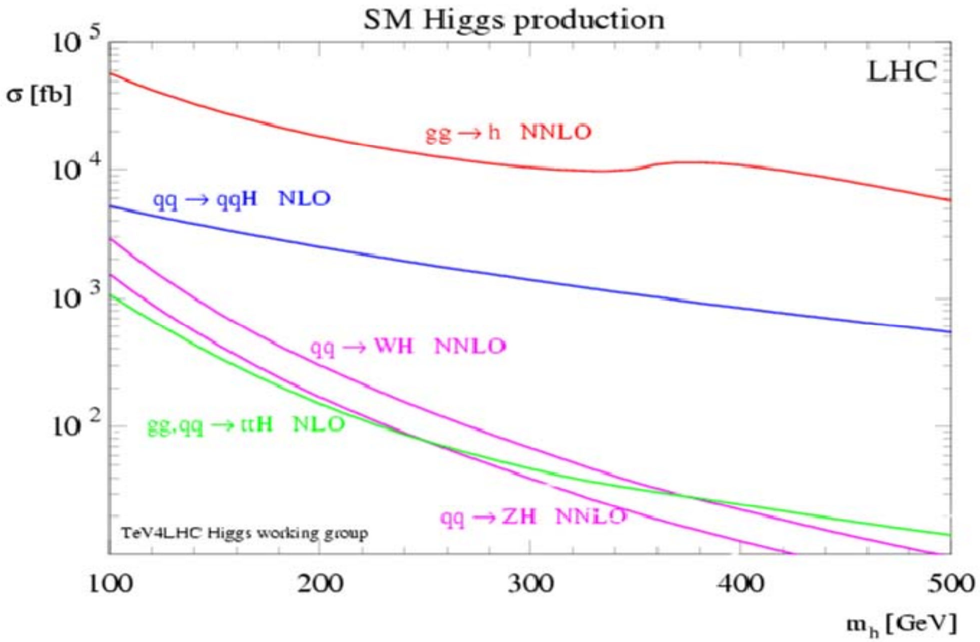
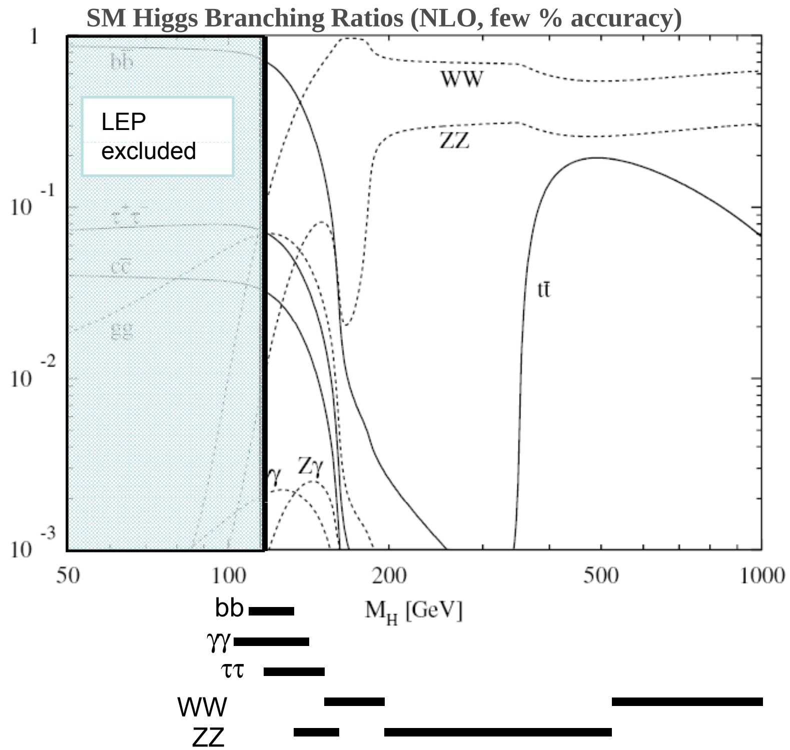
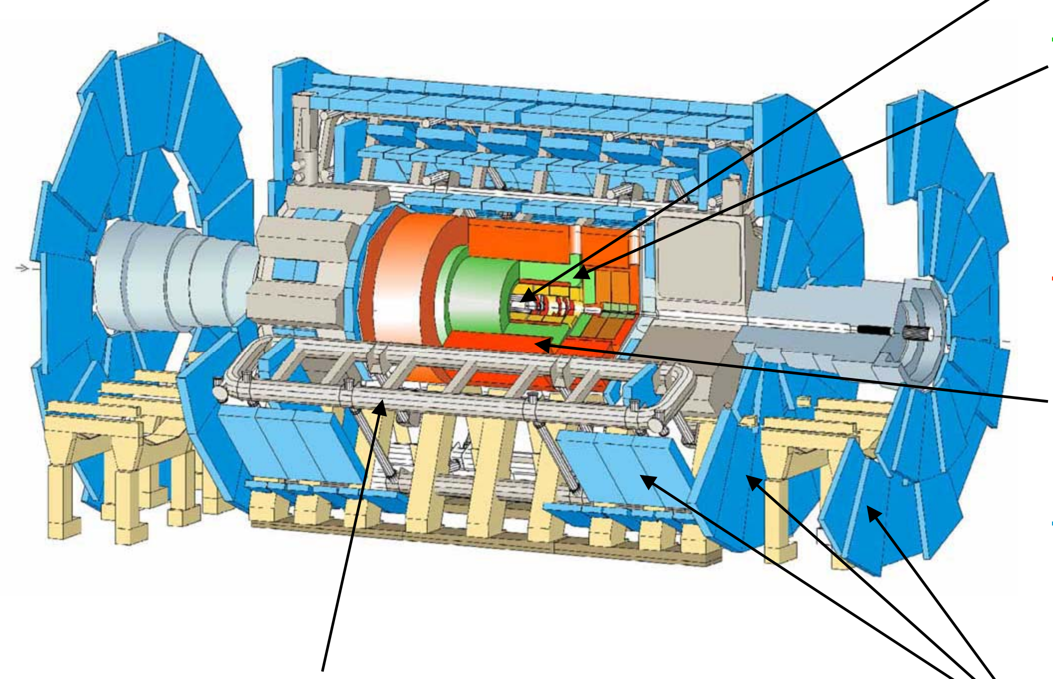




The ATLAS Detector

Primary features:
- High hermeticity (e.g. for missing Et:ν...)
- Excellent ECAL energy resolution
- Powerful inner tracking
- Efficient muon ID and momentum meas.
- Energy scale: e/γ~0.1%,μ~0.1%,Jets~1%



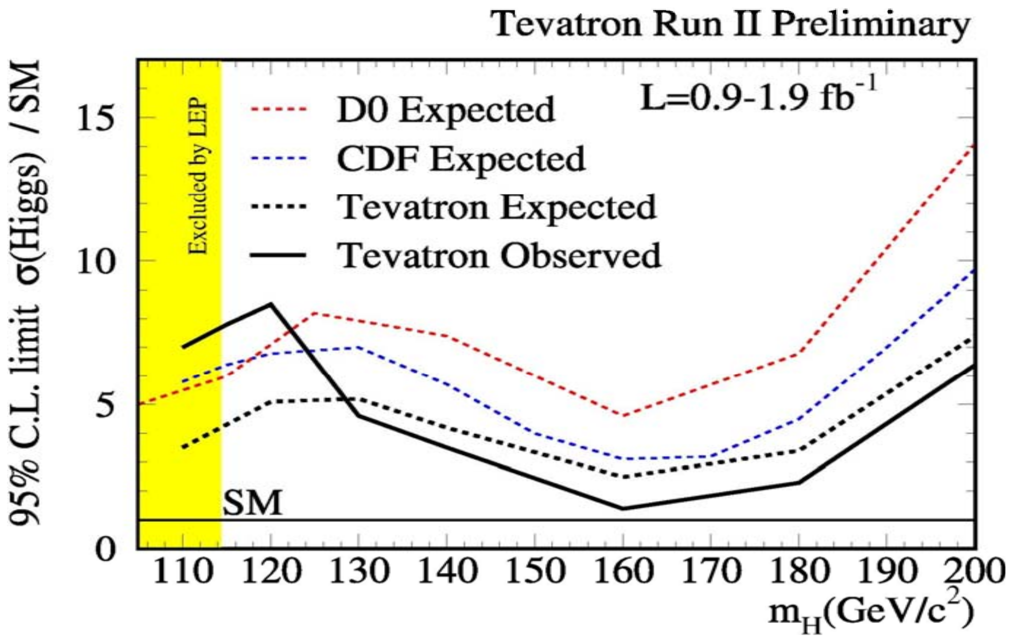
Inner Detector: pixels, silicon strips, transition radiation tracker surrounded by SC solenoid B=2T (e.g. $H \to bb$)

EM Calorimeters: Pb/LAr $\sigma/E \sim 10\%/\sqrt{E}$. $e^{\pm}$,γ identification, angular resolution γ/jet & γ/π0 separation (e.g. $H \to \gamma\gamma$, $H \to ZZ \to 4e$)

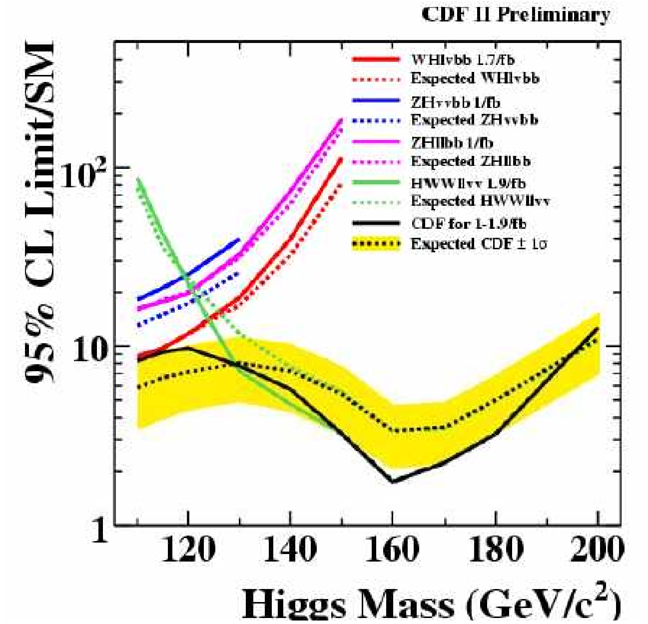
Hadronic Calorimeters: Fe scint. Cu-LAr). $\sigma/E \sim 50\%/\sqrt{E}+0.03$ Jet, ETmiss measurements (e.g. $H \to \tau\tau$, $H \to bb$)

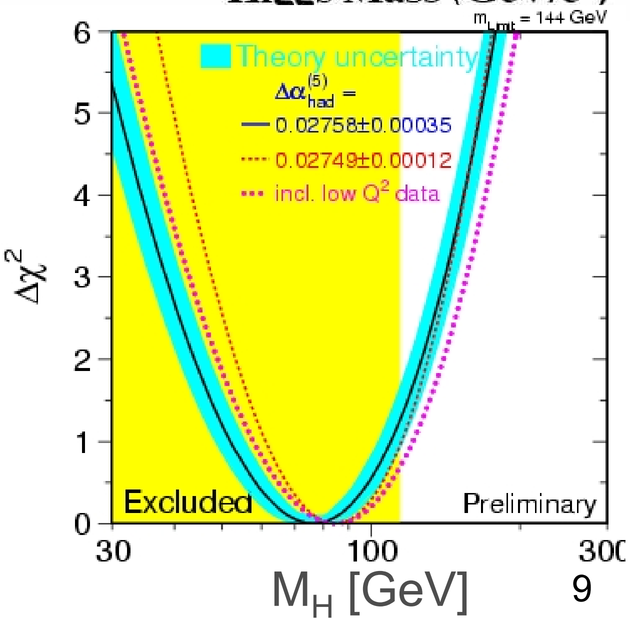
Muon Spectrometers: precision tracking drift chambers and trigger chambers $\langle B \rangle = 0.6T$, $\sigma/pT \sim$ 7-10% at 1 TeV (e.g. $H,A \to \mu\mu$, $H \to 4\mu$)

Latest from Tevatron



(95% CL on Higgs production cross-section normalised to SM)





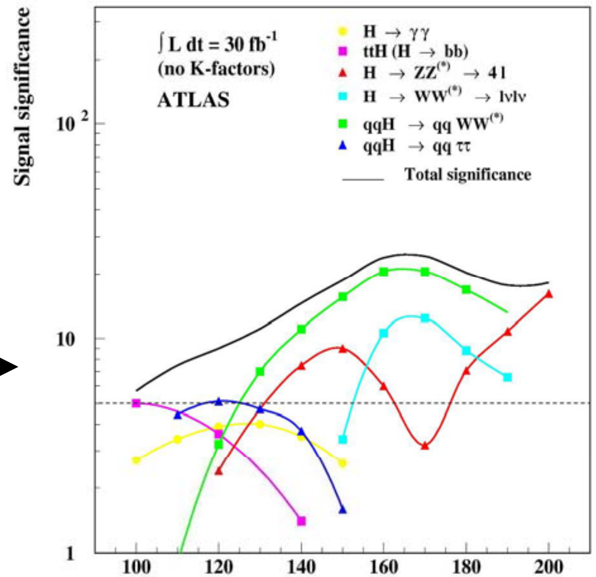
- CDF has roughly half it's planned luminosity gathered already.
- Together with D0, they may soon be able to exclude a Higgs around M_H~160 GeV.
- Consider also LEPEWWG: M_H<182 GeV (including LEP2 M_H>114.4 GeV)

→ Suggests a low mass Higgs.

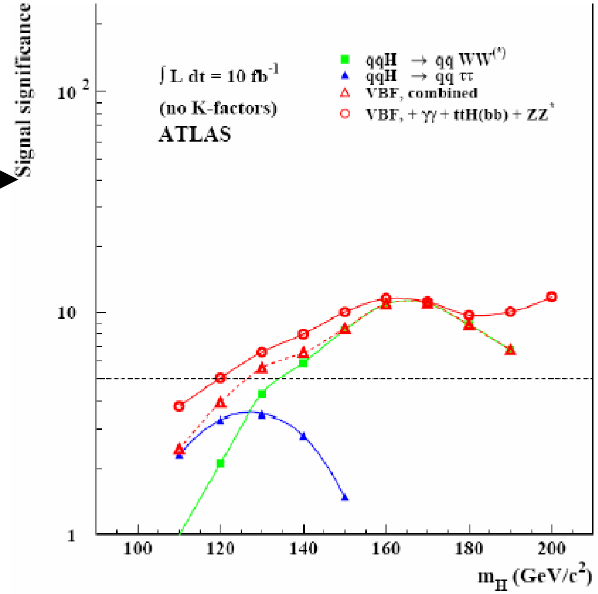
ATLAS SM Higgs Sensitivity

- Caveats:
  - Production cross-sections here are only LO.
  - Updated analyses, alternative generators, full G4 simulation: coming December 2007.

- ATLAS should make a light Higgs discovery (M_H<180 GeV) with $\int Ldt$=30 fb^{-1}.
- Discovery in the region M_H<120 is clearly the most challenging & will probably require several channels to be combined.



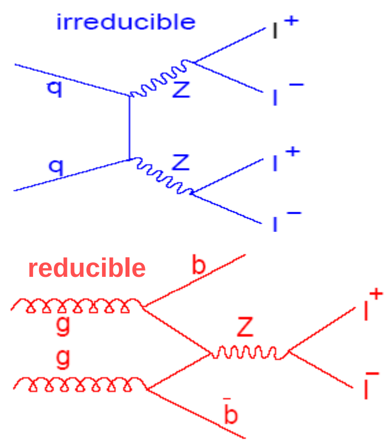
- ATLAS could make a discovery with much less luminosity, given favourable M_H.
- By combining VBF,γγ,ttH→bb,ZZ*, discovery of a Higgs M_H >120 GeV could be made at $\int Ldt$=10 fb^{-1}.



- $2M_Z$<M_H<500 GeV: H →ZZ→4ℓ gold-plated channel « easy »

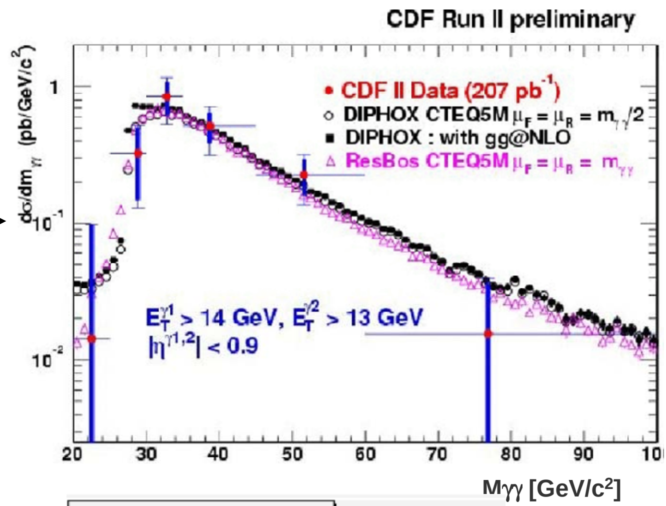
$H \rightarrow ZZ^* \rightarrow 4\ell^{\pm}$

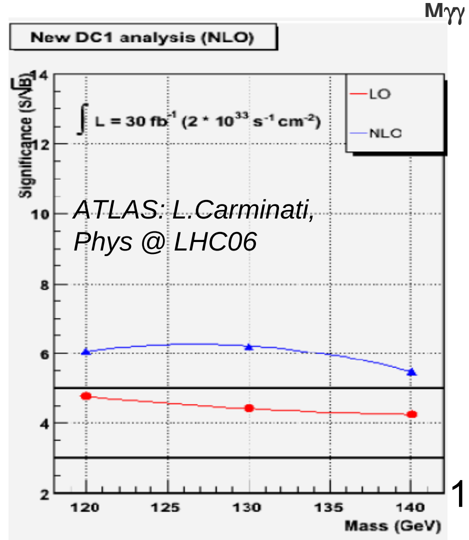
- Features:
  - Clean signature (but low stats: $\sigma \times BR(H \rightarrow 4l)$ ~3-11fb for M_H=130-200 GeV).
  - Benchmark channel for detector performance: ATLAS must have good EM energy resolution, combined with good momentum resolution.
  - Mass peak can be produced, 4e, 4μ, 2e2μ differ by resolution; typically ~1.5 - 2 GeV.
- Backgrounds:
  - irreducible: $ZZ^*/\gamma^* \rightarrow 4l$ continuum ($qq \rightarrow ZZ^*/\gamma^*$ known @ NLO. 20% added to account for $gg \rightarrow ZZ^*/\gamma^*$)
  - reducible: $tt \rightarrow 4l+X$, $Zbb \rightarrow 4l+X$ (non-isolated leptons, high impact parameter)
  - ZZ background is dominant after selection.
  - Get background shapes & normalisation from data to minimise PDF/Luminosity uncertainties.

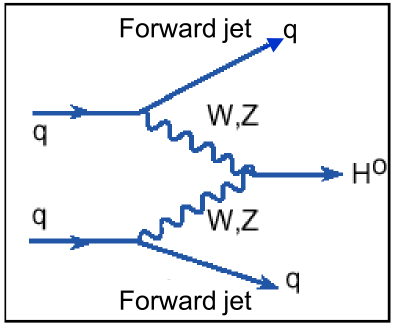


$H \rightarrow \gamma\gamma$

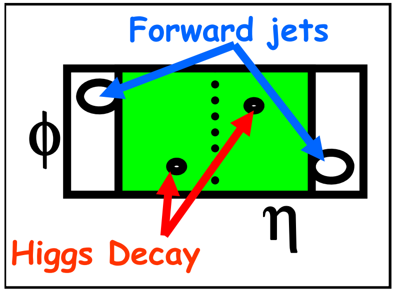
- Features:
  - Narrow mass peak over smooth background, region of interest M_H<140 GeV.
  - Benchmark channel for detector performance: ATLAS EM Cal resolution and primary vertex determination. Powerful particle ID required to reject jets in backgrounds (rej. >10^3 for ε_γ=80%)
- Backgrounds:
  - Irreducible $\gamma\gamma$ continuum :
    - Born($qq\rightarrow\gamma\gamma$), Box($gg\rightarrow\gamma\gamma$) ,q Brehms. ($qg \rightarrow q\gamma \rightarrow q\gamma\gamma$)
    - $\gamma\gamma$ background computed at NLO (agrees with Tevatron).
  - Reducible:
    - jj or γj where jet is misidentified as γ
- Event selection:
  - Isolated photons (calorimeter and tracking cuts)
  - Higgs z-vertex reconstruction:
    σz=40μm (L=$2.10^{33}cm^{-2}s^{-1}$); σz=1.6cm (L=$10^{34}cm^{-2}s^{-1}$)
  - Fine calo segmentation for π^0 rejection
- Recovery of conversions
  - ~30-40% of photons convert in the inner detector.
- Significance (30 fb^{-1}):
  - new(NLO):6.3
  - Improvement expected from likelihood analysis.

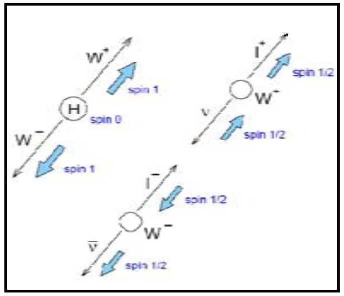






Vector Boson Fusion

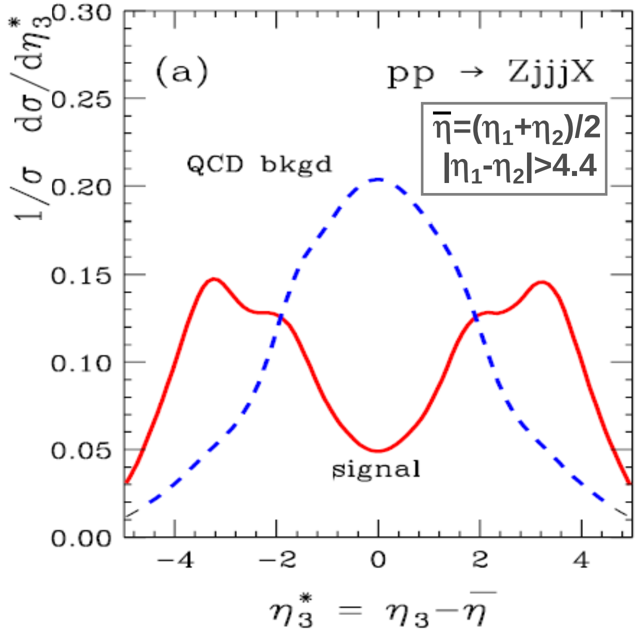


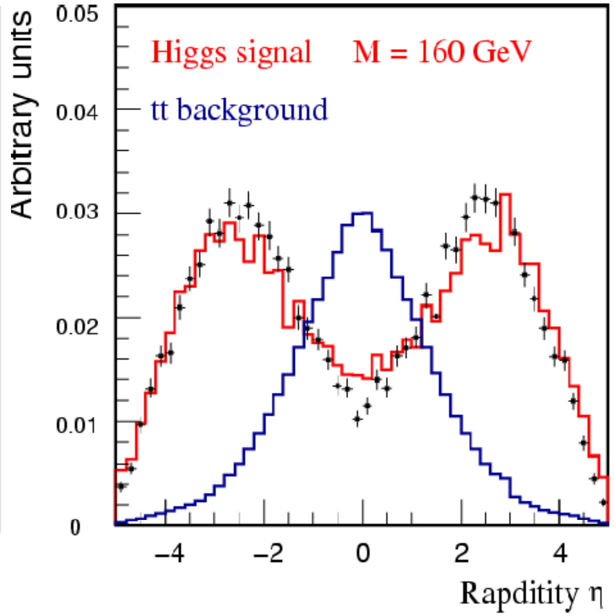


Features:

- 2nd most important production process (σ~10-20% of gg fusion)
- H decay products between two forward tag-jets.
- No central jets (no q-q colour exchange).
- Leptonic final state: leptons are spin correlated → for lνlν final state, l+,l- in same direction.

Zeppenfeld et al.

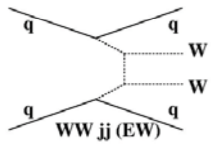


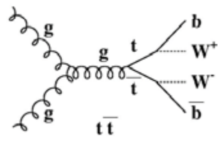


- Look for:
  - $H \rightarrow \tau\tau$, WW
- Event selection:
  - $\eta_{j1} \cdot \eta_{j2} < 0$
  - $|\Delta\eta_{jj}| > 3.5 - 4$
  - $M_{jj} > 500–700$ GeV
- Pile-up may give fake central jets, also harder to identify tag-jets.
- VBF may not be viable at high luminosity.

VBF H→WW

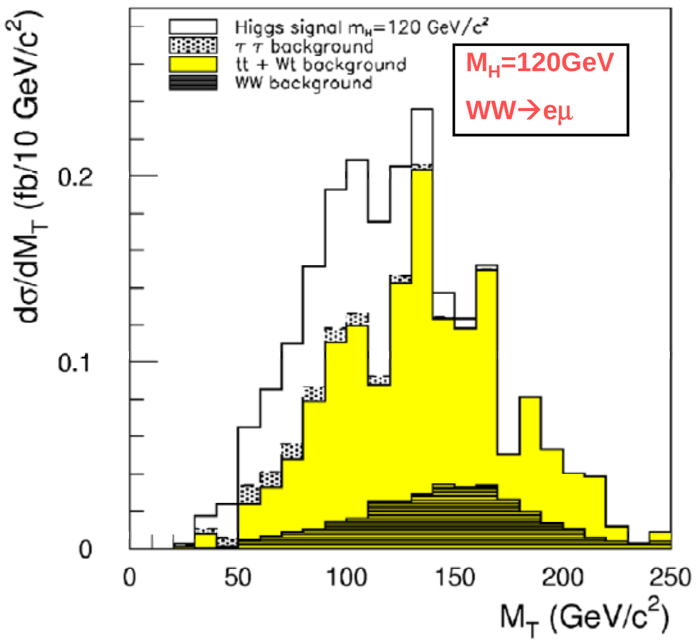
- Main backgrounds: WWjj, tt

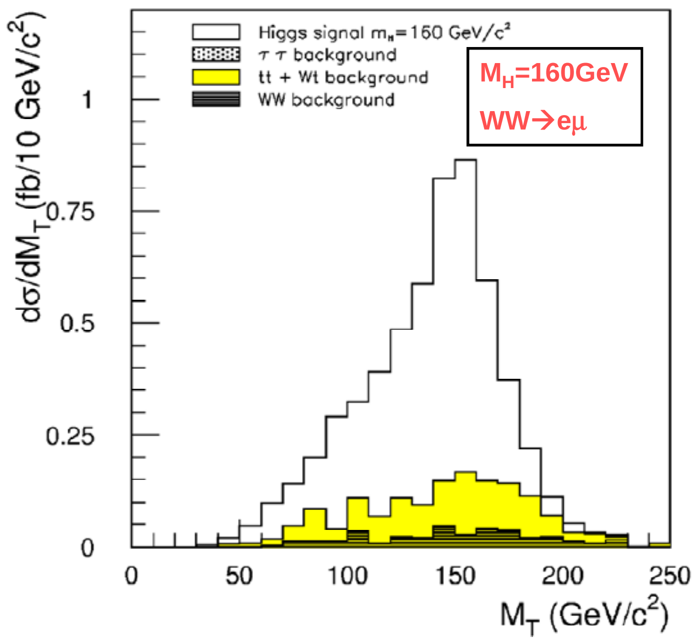




- H→WW→lνjj
  - Sig 4.6 at M_H=160 GeV for $\int Ldt=30\ fb^{-1}$
- H→WW→lνlν
  - No mass peak as two missing momenta.
  - Transverse mass $m_T = \sqrt{2\ P_T^{\ell\ell} \not{E}_T\ (1 - \cos \Delta\varphi)}$
  - Sig > 5.0 for M_H ≈125-190 GeV for $\int Ldt=30\ fb^{-1}$

Background uncertainty 7-10%



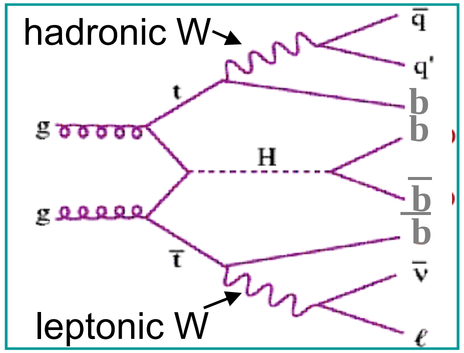


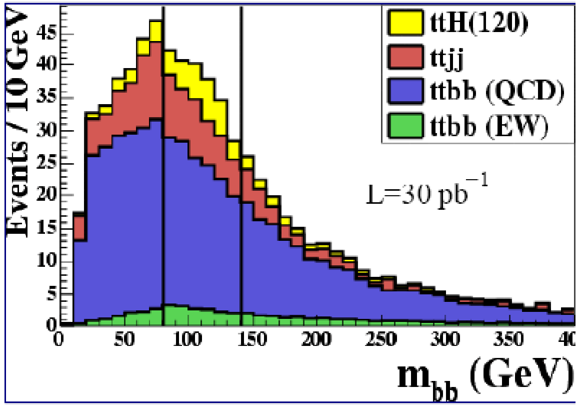
ttH H→bb

- Features:
  - Attractive due to large BR(H→bb) at M_H<130 GeV.
- Combinatoric background:
  - There are many ways to combine objects in the event

    → Mass peak resolution quite low.
- Physics backgrounds:
  - Backgrounds must be determined from data, σ(ttjj) dependent on scale choice.
  - Shape (highly dep on mistagging): use random tagging to estimate shape error.
  - Normalisation: from the sidebands.
  - ttjj: b-tagging optimised to reject light jets.
  - ttbb (EW/QCD): 2 extra b-jets are not from a Higgs (typically QCD gluon radiation).

    →Kinematic info can then be used to reject bg.
  - S/√B = 2.8





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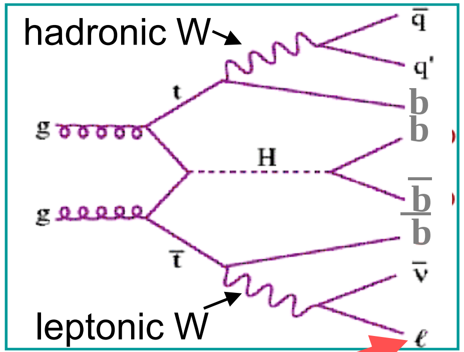
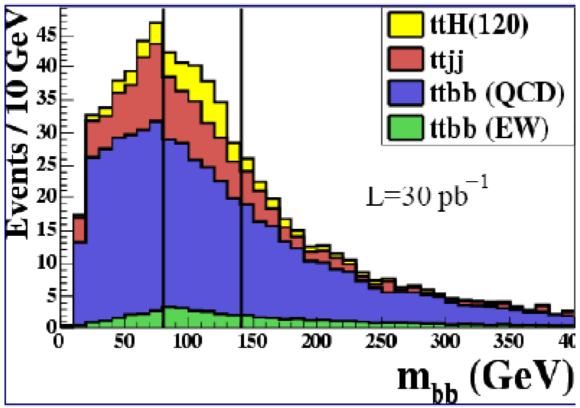


Semi-leptonic: trigger on high Pt isolated e,μ



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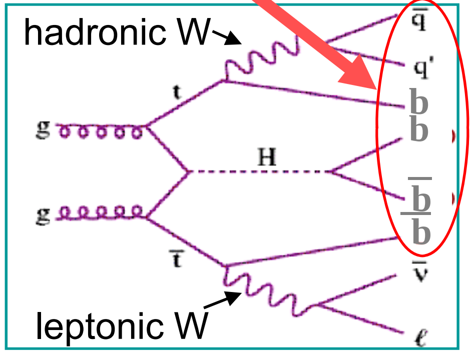

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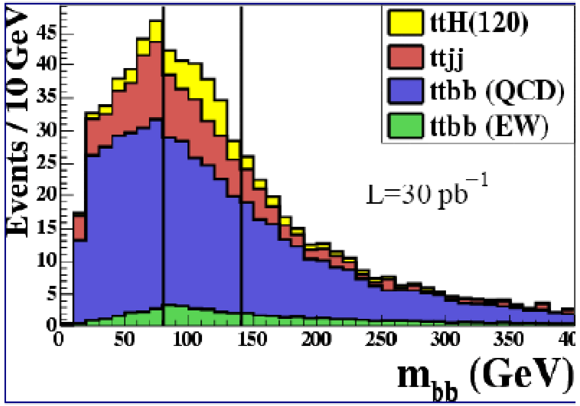

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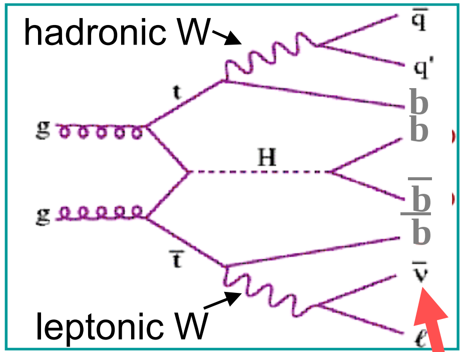
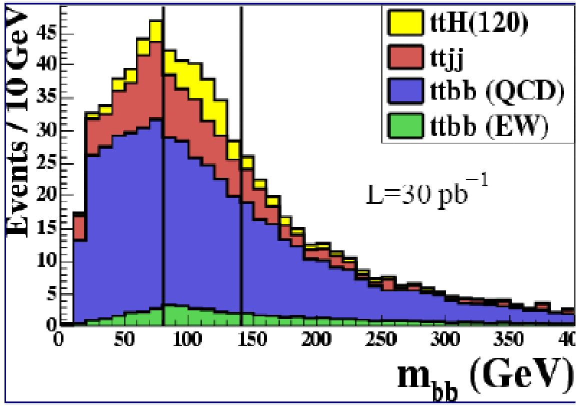


Semi-leptonic: trigger on high Pt isolated e,μ

Missing Et used to reconstruct neutrino



ttH $H \to bb$

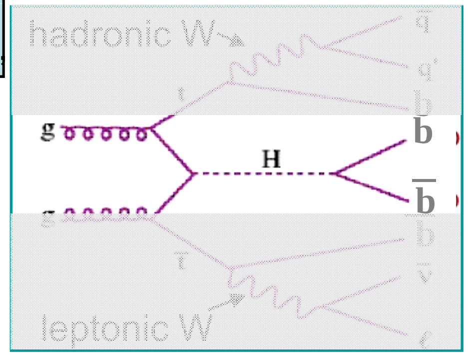
- Features:
  - Attractive due to large BR($H \to bb$) at M_H<130 GeV.
- Combinatoric background:
  - There are many ways to combine objects in the event

    → Mass peak resolution quite low.
- Physics backgrounds:
  - Backgrounds must be determined from data, σ(ttjj) dependent on scale choice.
  - Shape (highly dep on mistagging): use random tagging to estimate shape error.
  - Normalisation: from the sidebands.
  - ttjj: b-tagging optimised to reject light jets.
  - ttbb (EW/QCD): 2 extra b-jets are not from a Higgs (typically QCD gluon radiation).

    →Kinematic info can then be used to reject bg.
  - $S/\sqrt{B}$ = 2.8

Select events with high jet multiplicity (≥6), at least 4 b-tagged jets.

Require W,t's to be reconstructed.



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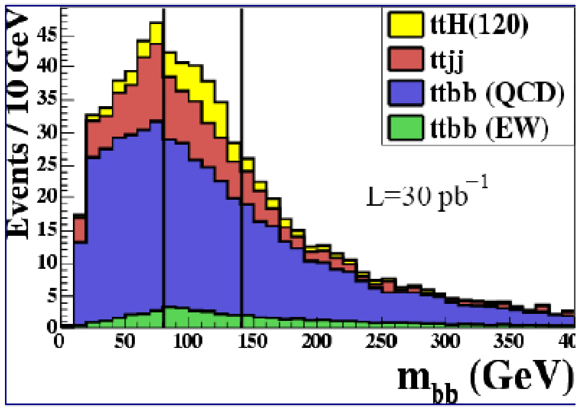
Missing Et used to reconstruct neutrino



ttH $H \rightarrow bb$

- Features:
  - Attractive due to large BR($H \rightarrow bb$) at M_H<130 GeV.
- Combinatoric background:
  - There are many ways to combine objects in the event

    → Mass peak resolution quite low.
- Physics backgrounds:
  - Backgrounds must be determined from data, σ(ttjj) dependent on scale choice.
  - Shape (highly dep on mistagging): use random tagging to estimate shape error.
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  - ttjj: b-tagging optimised to reject light jets.
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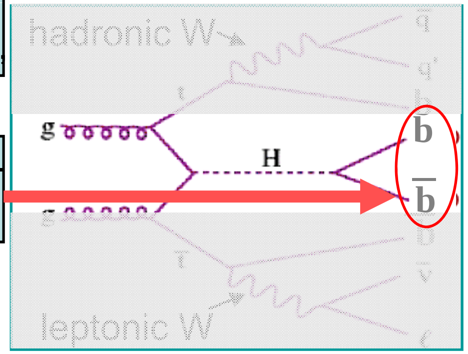
    →Kinematic info can then be used to reject bg.
  - $S/\sqrt{B}$ = 2.8

Select events with high jet multiplicity (≥6), at least 4 b-tagged jets.

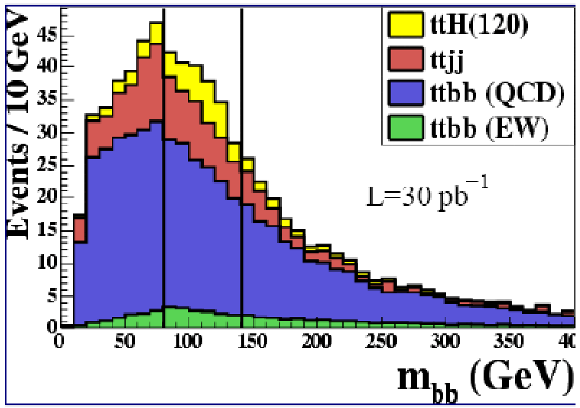
Require W,t's to be reconstructed

Use remaining b-jets for Higgs



Semi-leptonic: trigger on high Pt isolated e,μ

Missing Et used to reconstruct neutrino

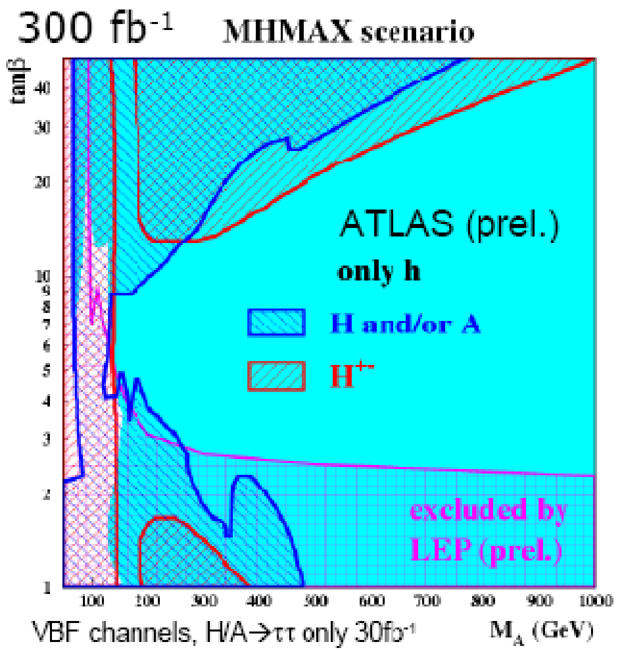


MSSM Higgs Discovery Potential

- MSSM theory predicts 5 physical Higgs bosons: h^0, H^0, A^0, H^+, H^- from two Higgs doublets.
- Higgs masses (to first order) are defined by two parameters:
  - ***tanβ*** ratio of 'vev' of 2 Higgs doublets
  - ***m_A*** mass of cp-odd Higgs A^0.
- Four points chosen in parameter space →

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 a scenario: coupling of h to b(τ) suppressed designed for VBF, h→ττ and tth,h→bb

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



MSSM Higgs Discovery Potential

- MSSM theory predicts 5 physical Higgs bosons: h^0, H^0, A^0, H^+, H^- from two Higgs doublets.
- Higgs masses (to first order) are defined by two parameters:
  - ***tanβ*** ratio of 'vev' of 2 Higgs doublets
  - ***m_A*** mass of cp-odd Higgs A^0.
- Four points chosen in parameter space
- If parameters are in fact in this region, only single SM-like Higgs will be observed.
- At least one Higgs should be found in all 4 CP conserving scenarios.
- Promising channels:
  - $A/H \Rightarrow \mu\mu, \tau\tau$; $H\pm \Rightarrow \tau\nu$

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 $gg \rightarrow h$, $h \rightarrow \gamma\gamma$, $h \rightarrow ZZ \rightarrow 4l$
Small a scenario: coupling of h to b(τ) suppressed designed for VBF, $h \rightarrow \tau\tau$ and tth,$h \rightarrow bb$

Name	M_{SUSY} (GeV)	μ (GeV)	M_2 (GeV)	X_t (GeV)	M_{gluino} (GeV)
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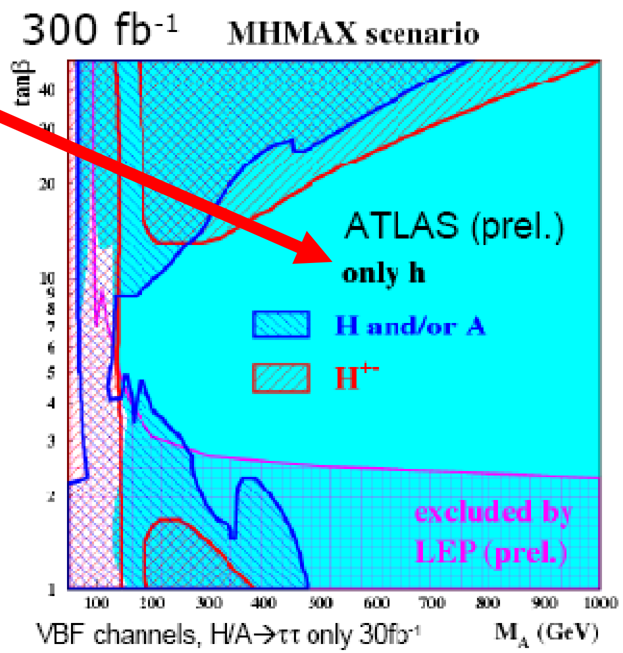
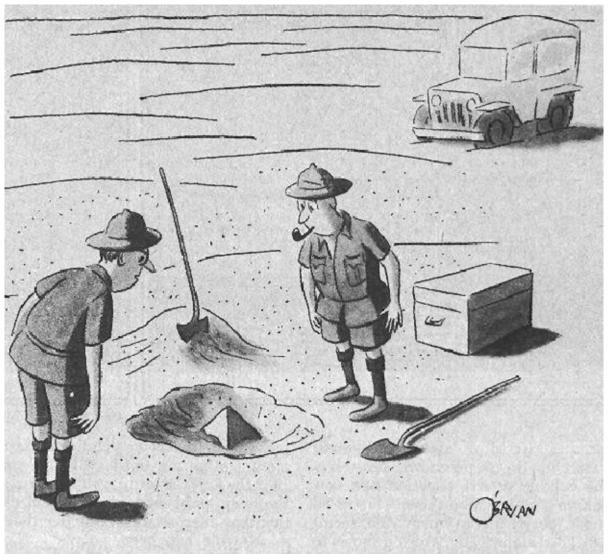


Conclusions

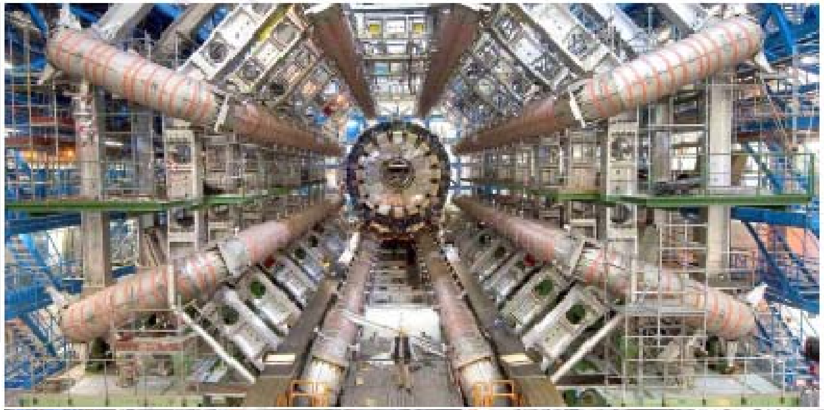
- SM searches: ATLAS provides discovery potential over the entire mass range of a SM Higgs boson with $30fb^{-1}$ of integrated luminosity.
  - Detector performance studies will be crucial.
  - Background shapes must be ascertained.
- MSSM searches: The whole MSSM parameter space is covered by at least one Higgs boson for $300fb^{-1}$ of integrated luminosity:
  - Most difficult region: moderate $\tan\beta$, large M_A.
  - If only one Higgs boson is observed, work is needed to distinguish between the SM and MSSM scenarios (e.g. looking at rates like: $R = \frac{BR(h \rightarrow WW)}{BR(h \rightarrow \tau\tau)}$ which may deviate from SM predictions at low M_A)…………………

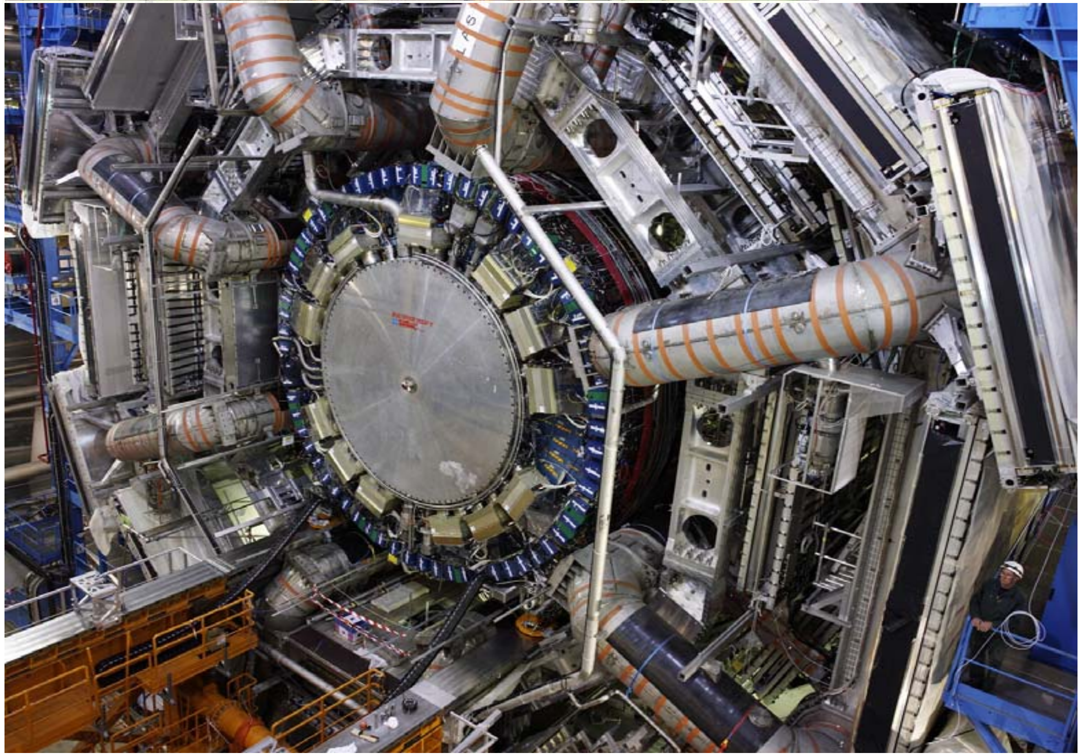


"This could be the discovery of the century. Depending, of course, on how far down it goes."

Finally…

- ATLAS is approaching completion.
- 7 TeV proton beams expected in Summer 2008.

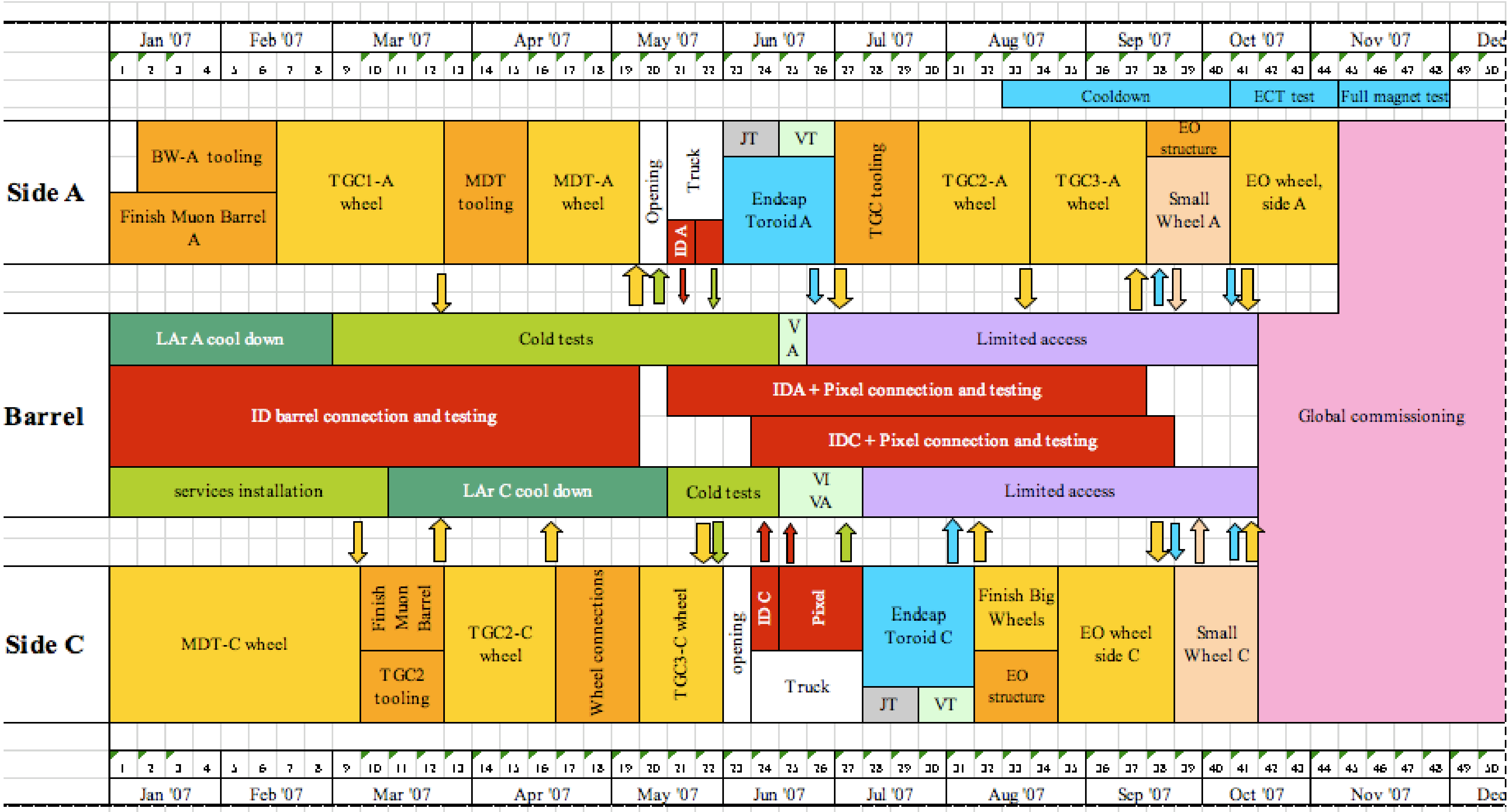




BACKUP MATERIAL

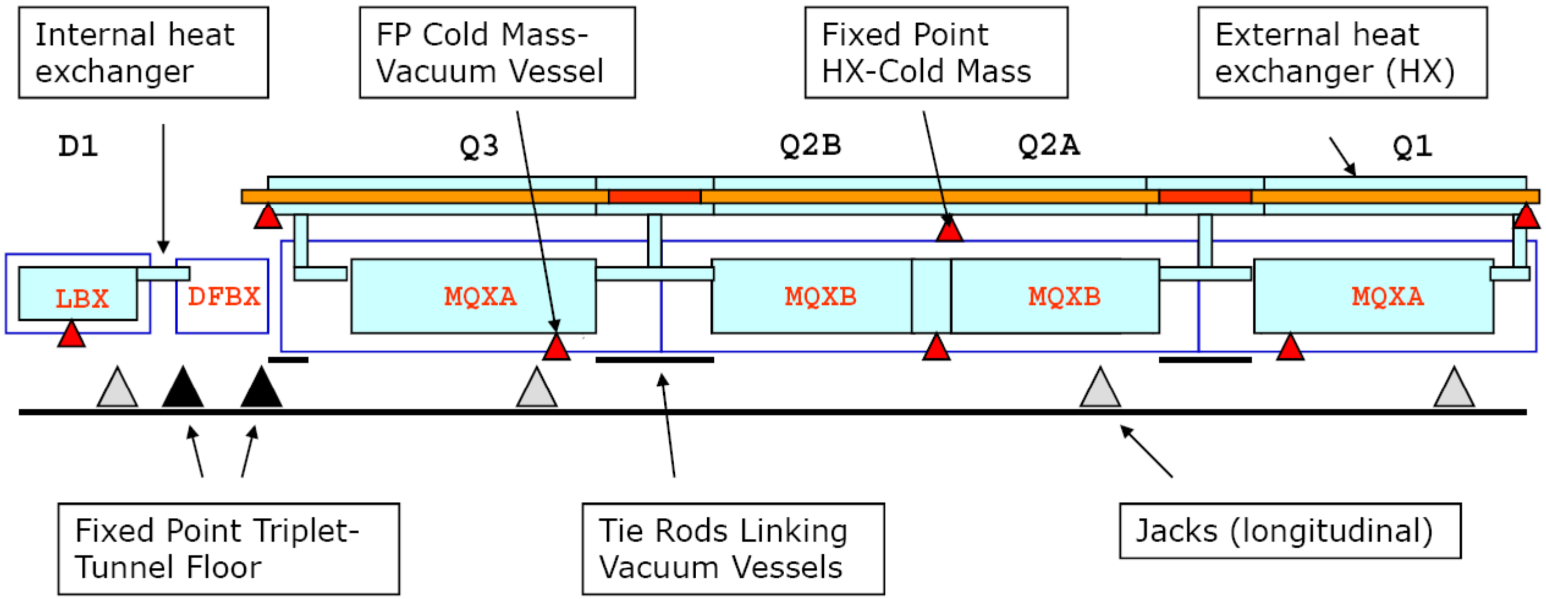
ATLAS Installation schedule version 9.1

M. Kotamäki, M.Ness
20-Apr-2007



Inner Triplet review: Jun07

- From FNAL: On Tuesday, March 27, a Fermilab-built quadrupole magnet, one of an “inner triplet” of three focusing magnets, failed a high-pressure test at Point 5 in the tunnel of the LHC accelerator at CERN.
- Weak points located in the anchoring to cold masses. To be reinforced on Q1, Q3 and DFBX.
- *Can be done in-situ*



ATLAS, CMS compared

SYSTEM	**ATLAS**	**CMS**
INNER TRACKER	Silicon pixels+ strips TRT $\rightarrow$ 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 $\rightarrow \sigma /p_T \sim 5\%$ 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