Max-Planck-Institut für Physik
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Higgs searches with leptons in ATLAS

LHC Days in Split • 2 - 7 October 2006 • Split, Croatia

Higgs searches in ATLAS - current status

The first evaluation of the Higgs discovery potential in ATLAS has been published already in 1999 (Technical Design Report, TDR).

Since then:

- The detector layout was modified, affecting detector performance.
- ATLAS software is approaching the final detector description.

  $\Rightarrow$ Necessary to update or improve the existing analyses.
  Also, some new, promising channels have been spotted.

$\Downarrow$

A busy period has started (Computing System Commissioning, CSC):

Demonstrate the physics readiness by detailed studies of key channels.

Studies are mainly concentrated to the preparation for the first data and the low-luminosity running period.

Final physics and performance notes to appear early next year.

Reconstructing Leptons in ATLAS

Why to look for leptonic signatures?

Leptons ($\equiv$ electrons and muons) are

- most efficiently reconstructed objects in the detector,
- with a very low fake rate
- and with the highest momentum resolution.

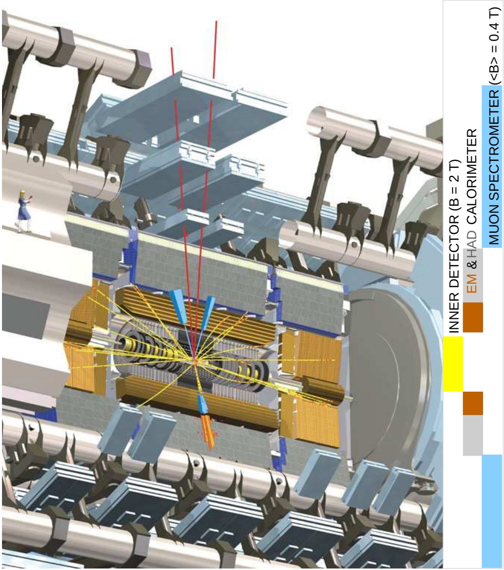
Lepton reconstruction performance can be well understood from data, using $Z \to e^+e^-$ and $Z \to \mu^+\mu^-$ processes as a reference.

$Z \to \mu\mu$: $\sim$ 40 000 events at 100 pb^{-1} (in few days - weeks)
- statistics similar to TEVATRON today.

$\Downarrow$

Some of the cleanest Higgs signatures are those having leptons as the final Higgs decay products.

Lepton reconstruction in ATLAS detector



Muons:

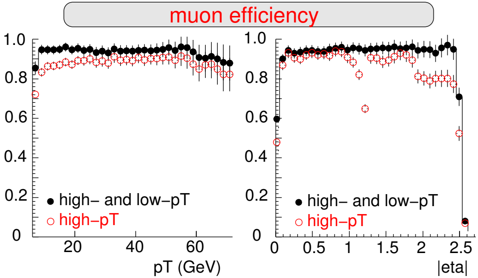
- Muon spectrometer track (MS: trigger + drift-tube chamb.), can be combined with the inner detector track. (ID: silicon detector + TRT)
- Low-p_T muons: ID track combined with MS hits.

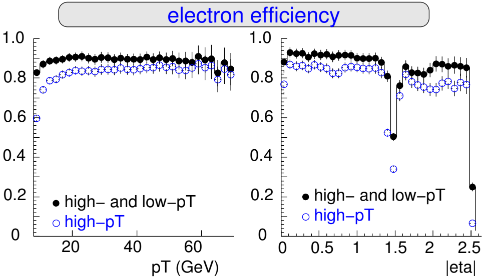
Electrons:

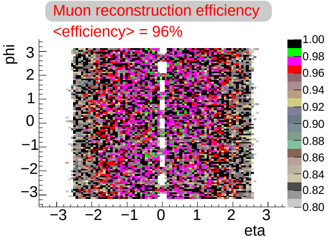
- Shower-shape analysis in the fine-granularity calorimeter, clusters are always matched with the ID track.
- Low-p_T electrons: ID combined with clusters.

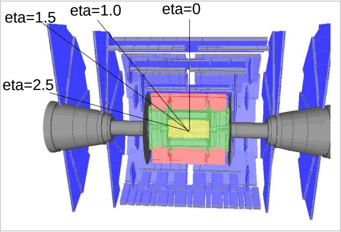
Isolation criteria (given by the calorimeter or by the inner detector): suppressing leptons which come from jets.

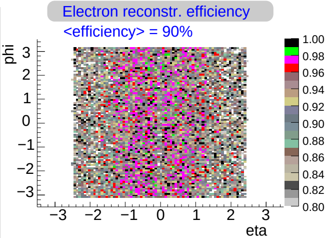
Lepton reconstruction efficiency







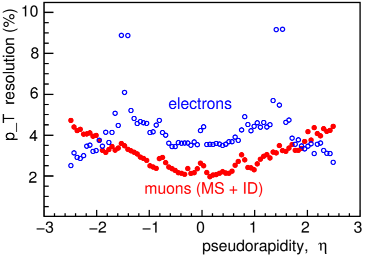


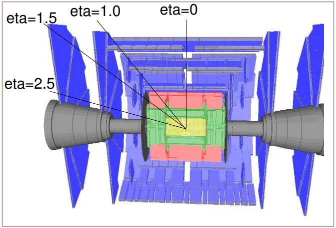


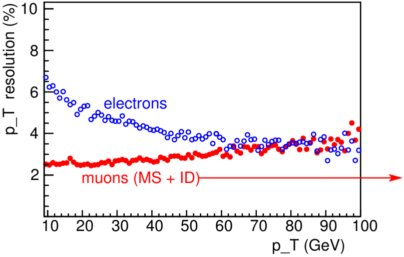
Low-p_T algorithms help to improve the reconstruction efficiency.

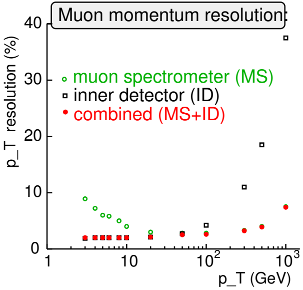
Electrons more difficult than muons (Brehmsstrahlung, dead material).

Lepton momentum resolution







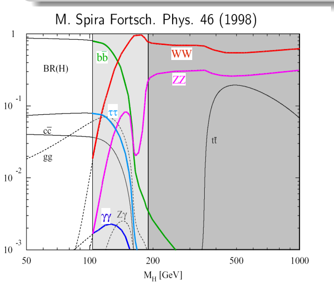


(TDR: $<\epsilon>$=95%, p_T-res.=3%) $\rightarrow$ Performance now degraded w.r.t. TDR. Reconstruction algorithms still to undergo slight improvements.

Leptonic Higgs Signatures

Menu of leptonic Higgs decays

Standard Model Higgs boson:



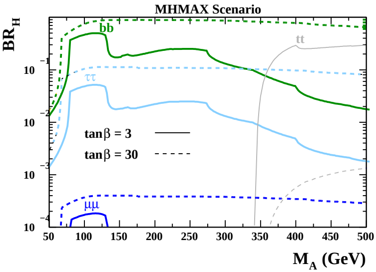
Purely leptonic decay:

- $H \to ZZ^{(*)} \to (\ell^+\ell^-)(\ell^+\ell^-)$

Leptons + missing transverse energy:

- $H \to W^+W^- \to (\ell^+\nu)(\ell^-\nu)$,
  VBF: $qqH, H \to W^+W^- \to (\ell^+\nu)(\ell^-\nu)$
- VBF: $qqH, H \to \tau^+\tau^- \to (\ell^+\nu\nu)(\ell^-\nu\nu)$

Heavy neutral MSSM Higgs boson:



Purely leptonic decay:

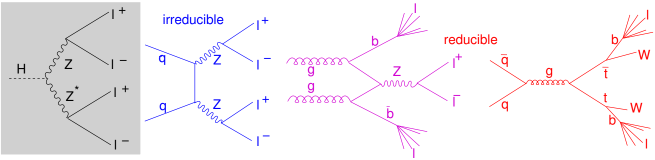
- $(bb)H/A \to \mu^+\mu^-$,
  most promising after the $\tau\tau$-mode.

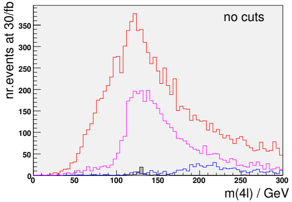
At large $\tan\beta$:
decays into WW, ZZ and $\gamma\gamma$ are suppressed.

$H \longrightarrow ZZ^{(*)} \longrightarrow (\ell^+\ell^-)(\ell^+\ell^-)$

Highly sensitive to the lepton reconstruction efficiency, $\epsilon_{4\ell} = (\epsilon_\ell)^4$.

$\epsilon_{4\mu}$=0.85, ϵ_{4e}=0.66





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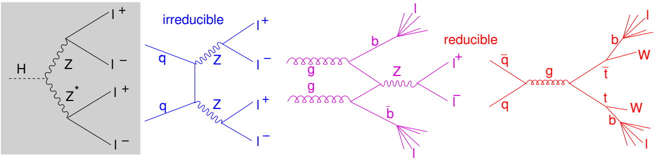
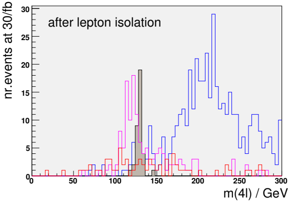
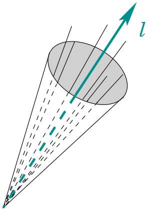
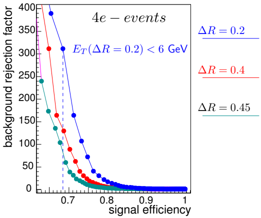
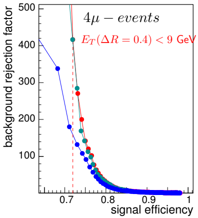




- Lepton isolation (cut on $E_T^{max}(\Delta R)$) optimized separately for electrons and muons - rejects most of the $t\bar{t}$ and $Zb\bar{b}$ events.







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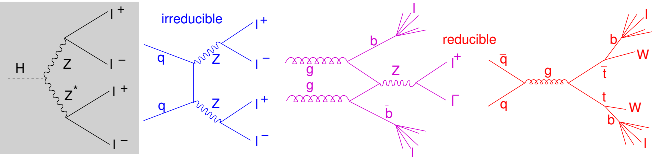

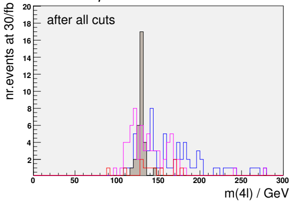

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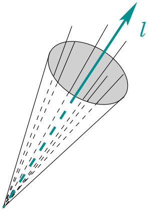
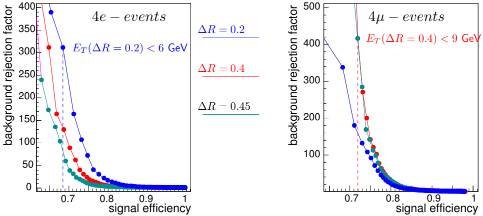
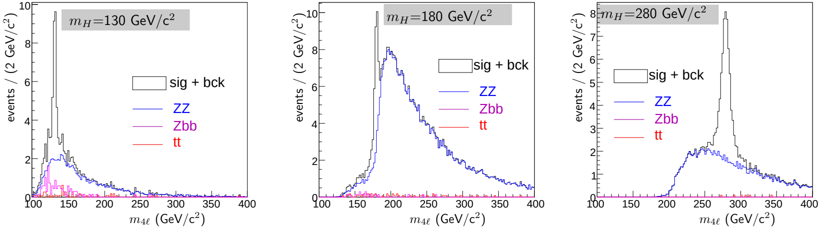




- Additional cuts: primary vertex, Z-mass, Z^*-mass, E_T^{miss}, $p_T^{4\ell}$; optimized for the highest signal significance.

$H \to ZZ^{(*)} \to (\ell^+\ell^-)(\ell^+\ell^-)$: Results for 30 fb^{-1}



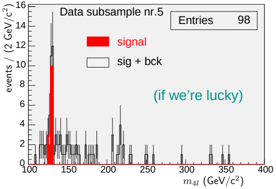
FULL SIMULATION	m_H =130 GeV ($\delta m = \pm 5$ GeV)	m_H =160 GeV ($\delta m = \pm 6$ GeV)	m_H =180 GeV ($\delta m = \pm 7$ GeV)	m_H =280 GeV ($\delta m = \pm 20$ GeV)
N_{signal} (gg+VBF)	21.5±0.1	26±1	28.1±0.3	67.4±0.1
$N_{qq\to ZZ}(\times 1.3$ f. $gg \to ZZ)$	11.3±0.3	11.4±0.3	27.3±0.5	40.4±0.6
$N_{Zb\bar{b}}$	2±2	2±2	1±1	0±2
$N_{t\bar{t}}$	0±0.4	0±0.4	0.5±0.4	0±0.4
Significance (no K)	5.0±0.3	5.5±0.5	4.7±0.2	8.8±0.4
$\mathcal{L}$ for 5σ discovery	30 fb^{-1}	25 fb^{-1}	37.5 fb^{-1}	11 fb^{-1}

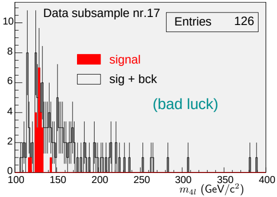
Differences between muon and electron reconstruction ⇒

FULL SIMULATION	$H \to 4e$	$H \to 4\mu$	$H \to 2e2\mu$	total
Significance m_H =130 GeV/c²	1.9	2.6	3.2	5.0

$H \rightarrow ZZ^{(*)} \rightarrow (\ell^+\ell^-)(\ell^+\ell^-)$: Ensemble test

Acctual 4ℓ-mass distribution at 30 fb^{-1} will look more like this:

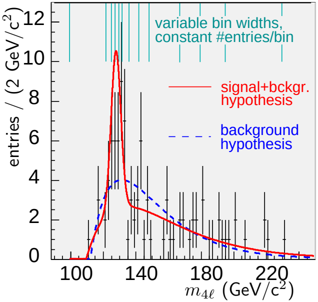




Small number of entries ⇒ variable bin width instead of equidistant bins for the fit of the (S+)B-functions.

Ensemble test of the fit performance (60 subsamples, 25 fb^{-1} each):

$$f_b\,(m_k) = N_b \cdot \alpha^2 (m_k - \epsilon) e^{-\alpha(m_k - \epsilon)};\quad f_s\,(m_k) = \frac{N_s}{\sqrt{2\pi}\sigma} \cdot e^{-\frac{(m_k-\mu)^2}{2\sigma^2}}$$



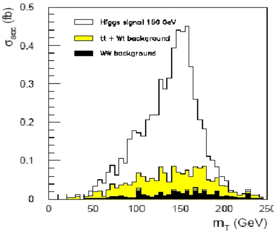
	fit results	remark
$N_{good\ \ fits}$	54	max. 60
$<N_s - N_s^{true}>$	2	$<N_s^{true}>=23$
$<N_b - N_b^{true}>$	3	$<N_b^{true}>=86$
$<\frac{\chi^2_b - \chi^2_{s+b}}{\chi 2_{s+b}}>$	1.6	hypothesis test
$<$Signf.$>$ $= \frac{N_s}{\sqrt{Var(N_s)}}$	2.9±0.6	"δm"-signf. 4.1±0.3

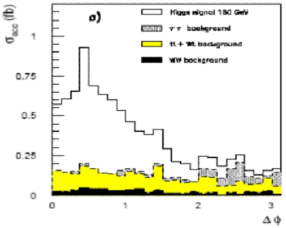
$H \to W^+W^- \to (\ell^+\nu)(\ell^-\nu)$

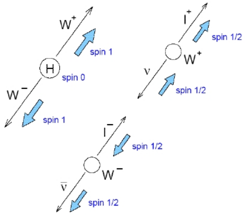
Dominant backgrounds	Rejection cuts
$qq/gg \to WW$	irreducible
$t\bar{t} \to WbWb$	$M_{\ell\ell}$ <300 GeV, b-jet veto
$Z \to \ell\ell$	$M_{\ell\ell} \notin$(82,98) GeV, E_T^{miss} >30 GeV
$W + jets$	no hard jets

- Azimuthal angle between the leptons, $\Delta\Phi_{\ell\ell}$ <1.5 (leptons emitted in the same direction, due to spin correlations).
- Transverse mass, $M_T = \sqrt{2p_T^{\ell\ell} \cdot E_T^{miss} \cdot (1 - \cos\theta)}$: $M_T \in (50, M_H+10)$ GeV.

Counting experiment: excess of signal over the expected background (good knowledge of background distributions needed).



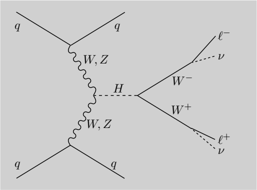


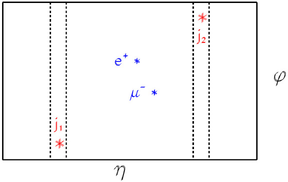


Recently: comparison of generators (PYTHIA, MC@NLO, SHERPA, ALPGEN) - good agreement observed

VBF: $qqH, H \to W^+W^- \to (\ell^+\nu)(\ell^-\nu)$

New promising signature from the Vector Boson Fusion (VBF) process.

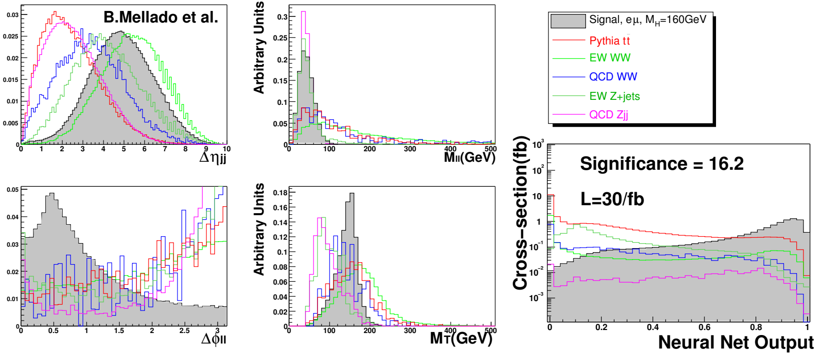




Typical topology:

- two forward jets
- leptons inbetween
- rapidity gap (no central jets)

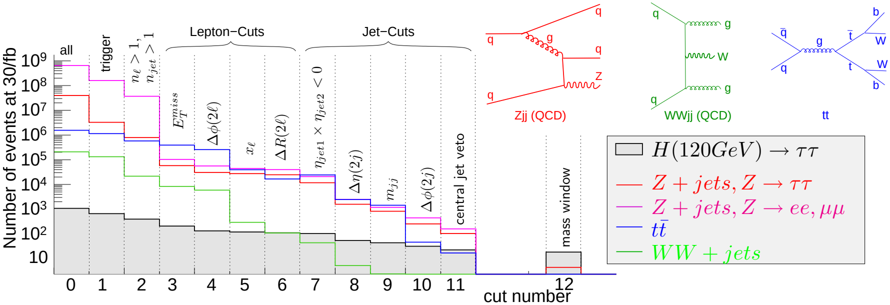
50% improvement of the signal significance with Neural Network:

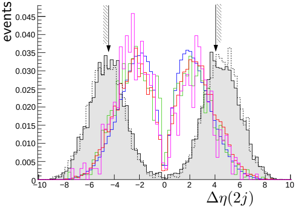


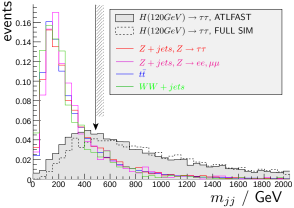
VBF: $qqH, H \to \tau^+\tau^- \to (\ell^+\nu\nu)(\ell^-\nu\nu)$

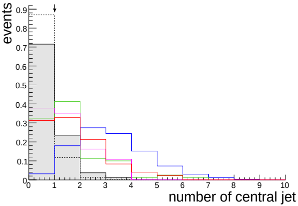
This channel is only visible in the VBF mode:

without the jet-cuts, the contribution from $Z \to \tau\tau$ is too large.





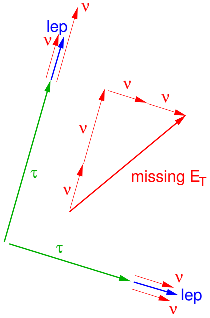


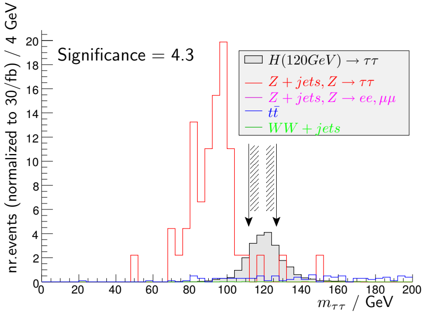


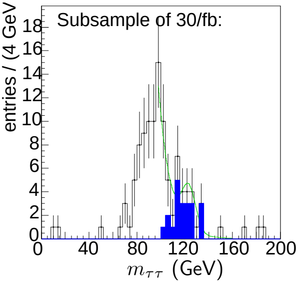
VBF: $qqH, H \to \tau^+\tau^- \to (\ell^+\nu\nu)(\ell^-\nu\nu)$

Mass peak reconstruted by means of the collinear approximation:

- $m_H \gg m_\tau$, so products of τ-decays fly in the direction of τ-s.
- Possible to calculate the four-momenta for τ-s.







Similar sensitivity observed also in the semi-leptonic channel, $H \to \tau\tau \to (\ell\nu\nu)(hadrons)$.

Remark on the VBF signatures

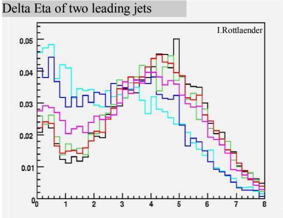
The searches in the VBF channels strongly rely on a good understanding of the jet distributions:

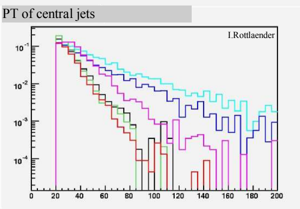
- Theory: underlying event uncertainties.
- Experiment:

  Pile-up affects the rapidity gap between two forward jets.

  Jet energy calibration (cross-section depends on the $p_T^{jet} - cuts$).

Comparison of different generators $\rightarrow$ hint for systematic uncertainties:





PYTHIA 6.323, new showering model; BUG

PYTHIA 6.323, old showering model; BUG

PYTHIA 6.403, new showering model

PYTHIA 6.403, old showering model

HERWIG

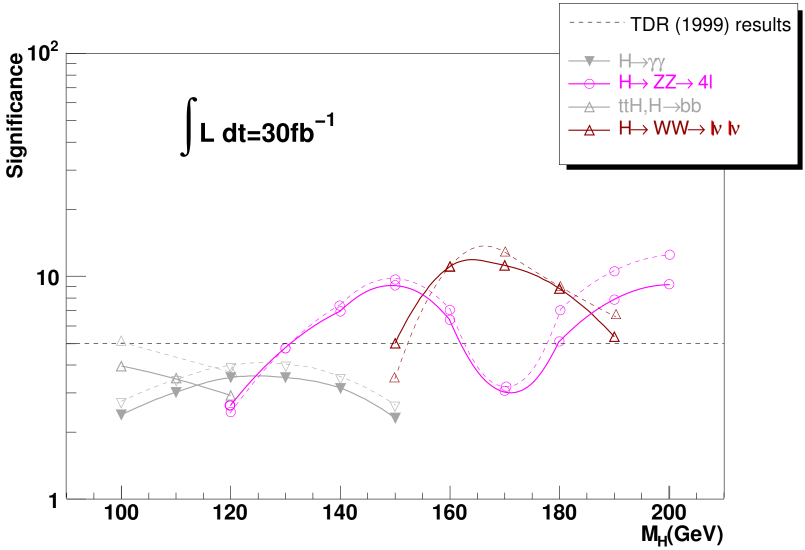
Final evaluation of the generators and det. perf. to be done with data.

($Z + jets$: handle for the jet distributions;

reference for the Higgs VBF cross-section (same depend. on the p_T^{jet} -cuts).

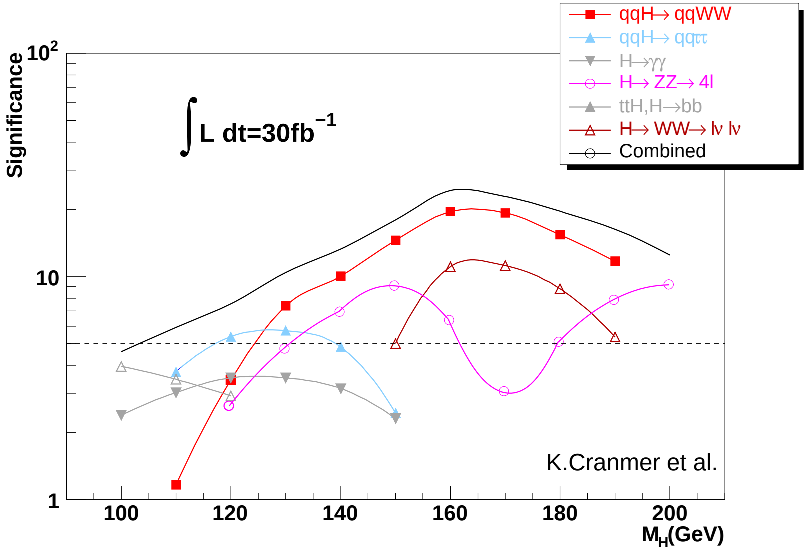
V.A.Khoze et al., hep-ph/0207365v3

SM Higgs discovery potential



- Performance of an up-to-date detector is similar to the TDR.

SM Higgs discovery potential



- Performance of an up-to-date detector is similar to the TDR.
- Vector boson fusion channels largely improve the discovery reach.

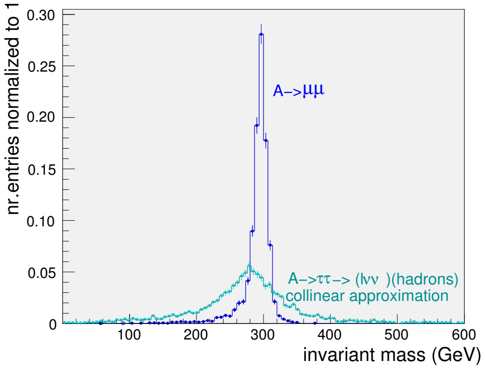
MSSM $(bb)A/H \to \mu^+\mu^-$

The power of the lepton reconstruction performance:

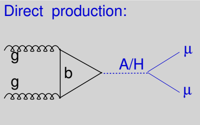
The most promising A/H signature is the $\tau\tau$-decay mode.

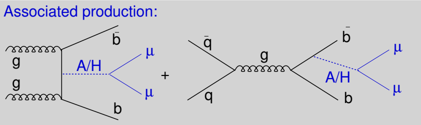
The $\mu\mu$-decays are suppressed by the factor $\frac{BR(A/H\to\mu\mu)}{BR(A/H\to\tau\tau)} = \left(\frac{m_\mu}{m_\tau}\right)^2 = \frac{1}{282}$.

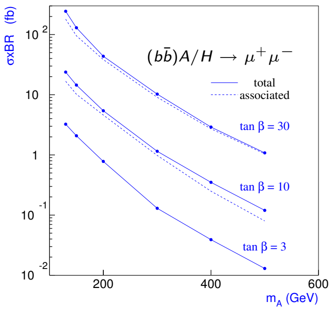
However, the muons provide a much narrower Higgs resonance:



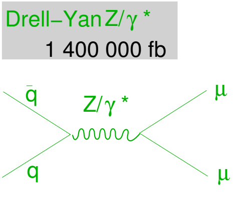
MSSM $(bb)A/H \rightarrow \mu^+\mu^-$: Event selection

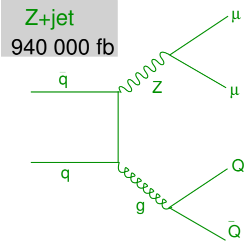


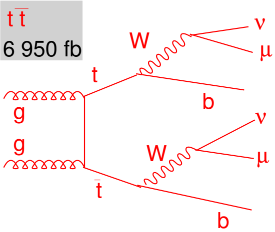




- Associated production with two b-jets dominates at larger $tan\beta$ values (>10).
- b-tag essential for the suppression of the $Z/\gamma^* \rightarrow \mu^+\mu^-$ background.
- $t\bar{t}$ suppressed by the cuts on E_T^{miss} and p_T^{b-jet} (b-jets more energetic than in signal).



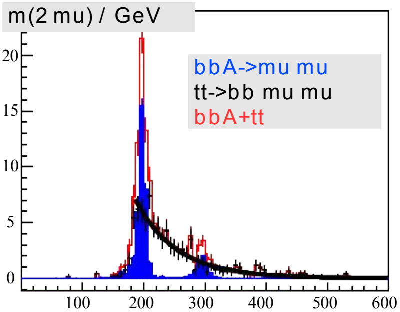


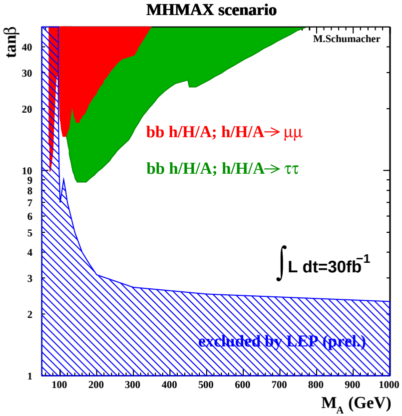


MSSM $(bb)A/H \rightarrow \mu^+\mu^-$: Results for 30 fb^{-1}

For the first time analysis performed using the full simulation:

Significance ($\tan\beta$=30)	200 GeV	300 GeV	350 GeV	450 GeV
ATLFAST	6.5	1.9	1.5	0.7
FULL	5.4	1.7	–	0.4





⇒ Only a factor of 2-3 worse than for the $\tau\tau$ decay mode.

Di-muon mode gives narrow resonances → separation of h/A/H peaks.

Outlook

The evaluation of the Higgs discovery potential for the key channels in ATLAS approaches the final stage.
Leptonic signatures have a large contribution to the overall signal significance, VBF channels are especially promising.

To Do List:

- Fine-tune the reconstruction alghoritms.
- Include the detailed information on the trigger performance.
- Study the pile-up effects (especially for VBF).
- Include the misalignment effects (mainly for the Higgs properties).
- Prepare for the detector calibration and background estimation with the first data.

  ...

  The ATLAS detector is growing large, installation on schedule. ⟶
- Pray for the first collisions.
- Enjoy (the sleepless nights with) the real data.