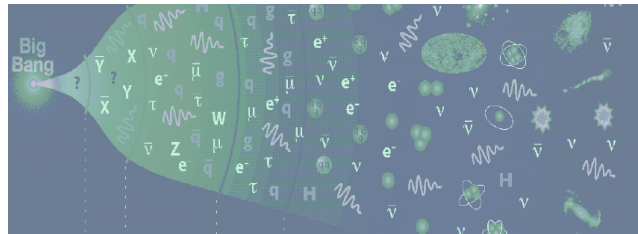




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How to discover the Higgs boson with the ATLAS detector at the LHC



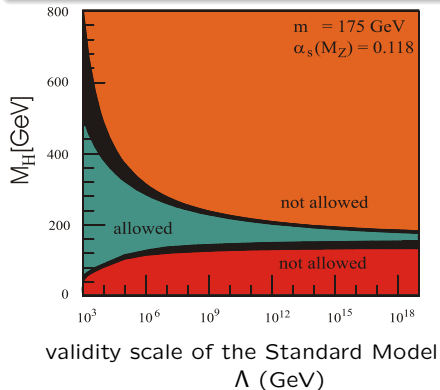
Science Week • 2007 December 3-7 • MPE, Garching

Higgs Boson in the Standard Model

The origin of particle masses can be explained in the standard model by electroweak symmetry breaking mechanism (Englert & Brout; P.W.Higgs), which predicts a new massive neutral spin-0 particle - the Higgs boson.

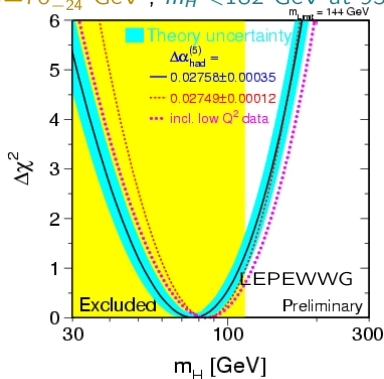
- Mass m_H of the Higgs boson is a free parameter of the theory.

Theoretical mass bounds:



Experimental limits (LEP, TEVATRON):

$m_H = 76^{+33}_{-24}$ GeV ; $m_H < 182$ GeV at 95% CL



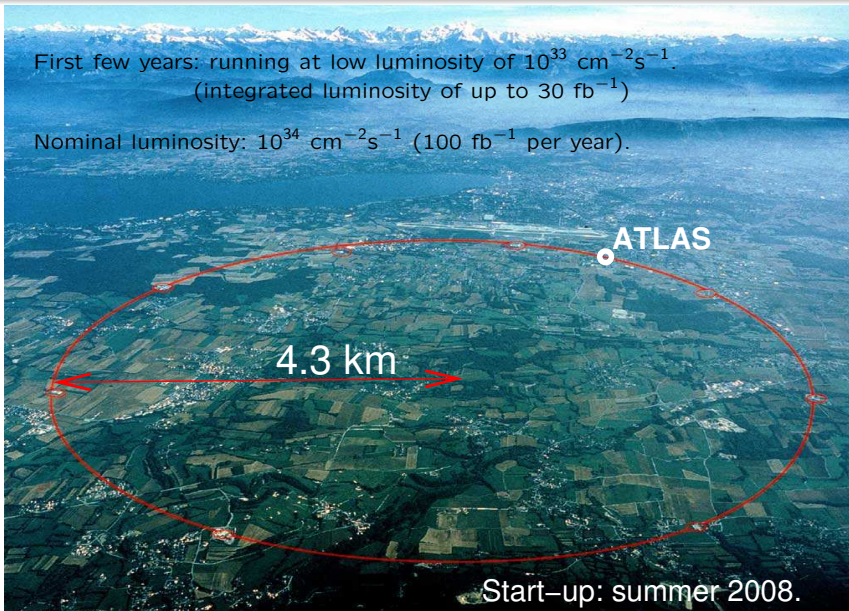


Large Hadron Collider at CERN

LHC: proton-proton collisions at 14 TeV centre-of-mass energy.

First few years: running at low luminosity of $10^{33} \text{ cm}^{-2} \text{ s}^{-1}$.
(integrated luminosity of up to 30 fb^{-1})

Nominal luminosity: $10^{34} \text{ cm}^{-2} \text{ s}^{-1}$ (100 fb^{-1} per year).





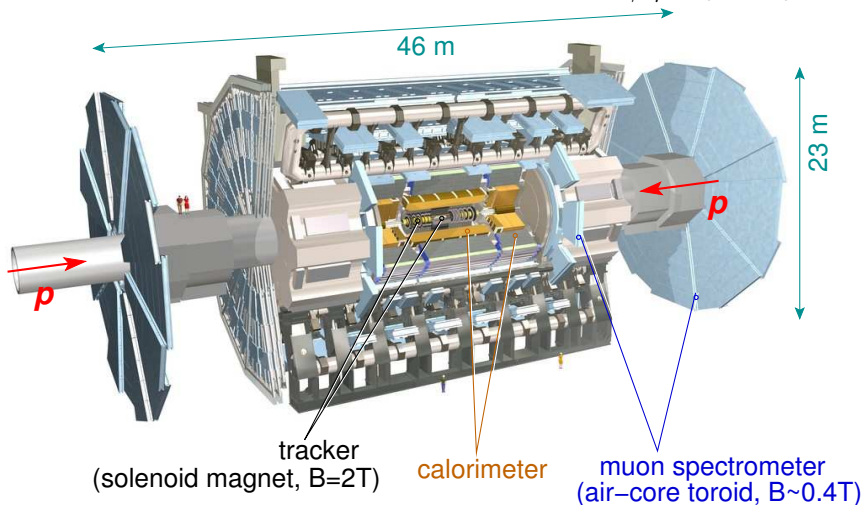
ATLAS Detector at the LHC

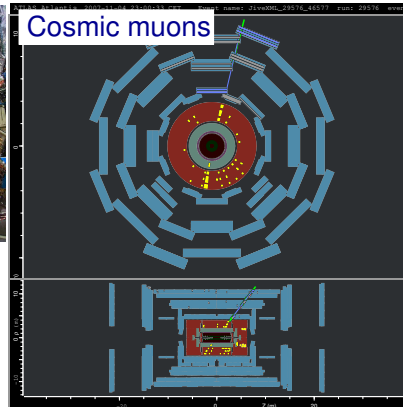
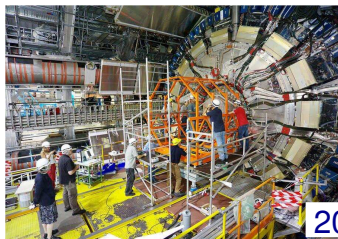
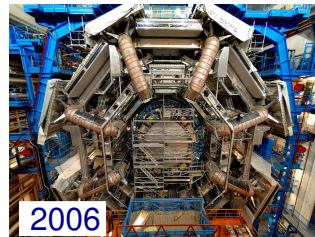
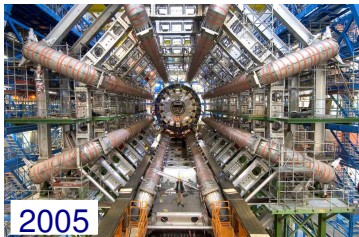
ATLAS design optimized for the Higgs search in a wide mass range:

Radiation hard detector components. Efficient and very selective trigger.

High-resolution, hermetic calorimetry → jet reconstruction, missing transverse energy.

Powerful particle identification and momentum resolution → e , γ , μ , b-jets, τ -jets.



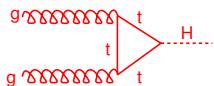


Detector commissioning with cosmic rays is fully under way.

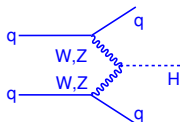
Ready for the collisions in April 2008.

Higgs Boson Production at the LHC

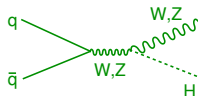
gluon-gluon fusion



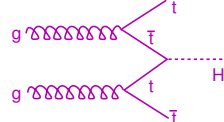
vector boson fusion, VBF



Higgs-Strahlung

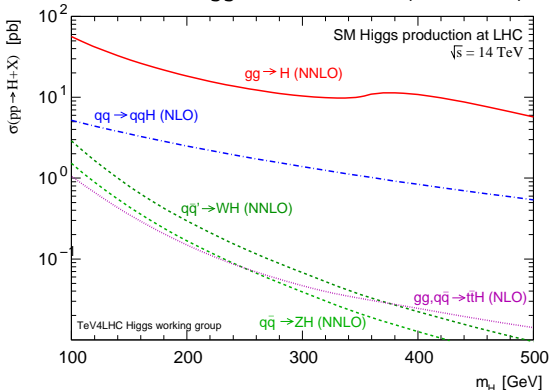


associated production



Higgs production cross-section, σ [pb]:

1000 - 100 000 Higgs bosons to be produced per year.

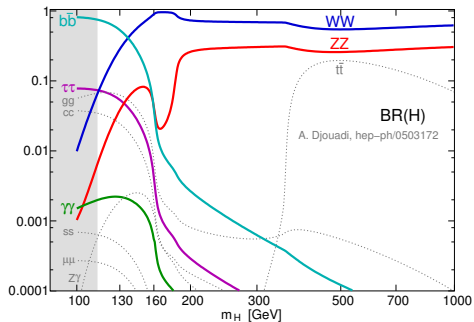


Backgrounds, σ [pb]:

Several orders of magnitude higher.

$t\bar{t}$	$\sim 0.8 \cdot 10^3$
$Z \rightarrow l^+ l^-$	$\sim 1.6 \cdot 10^3$
$W^\pm \rightarrow l^\pm \nu$	$\sim 1.7 \cdot 10^4$
$b\bar{b}$	$\sim 0.6 \cdot 10^7$
<i>multijets</i>	$\sim 0.3 \cdot 10^9$

Higgs Decay Modes



$m_H > 130$ GeV

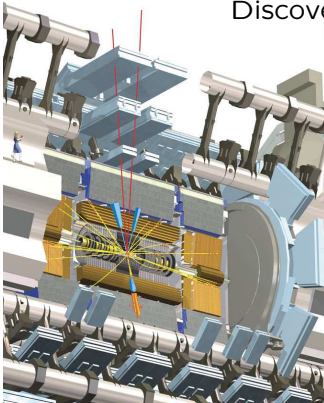
- $H \rightarrow ZZ^{(*)} \rightarrow 4l$:
Cleanest channel, high mass resolution;
"gold-plated" signature for $m_H > 2M_Z$.
- $H \rightarrow WW^{(*)} \rightarrow (l\nu l\nu, l\nu qq)$
Supplementary to the above channel.
Mass resolution limited.

$m_H < 130$ GeV

- $H \rightarrow b\bar{b}$:
Dominant decay, but hidden beneath the large QCD-background.
- $H \rightarrow \tau\tau$:
Observable only in the production mode via the vector boson fusion (VBF).
- $H \rightarrow \gamma\gamma$:
Very low branching ratio (loop-induced decays, via top- and W-loops),
but still very significant due to an excellent photon identification and resolution.

Key Higgs Signatures in ATLAS

Discovery reach is recently being re-evaluated.



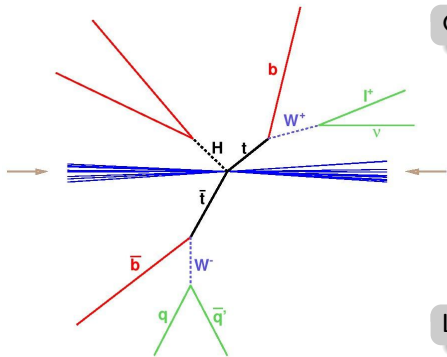
- Advanced Monte Carlo event generators.
- (N)NLO calculation of production cross-sections wherever possible.
- Detailed simulation of the complex detector response.

Millions of events simulated.

Simulation time: ~ 10 min per event.

⇒ Dedicated computing farms needed.

The only handle against the huge $b\bar{b}$ -background hiding $H \rightarrow b\bar{b}$ signal are two additional top-quarks from the $t\bar{t}H$ production mode.



Complex final state:

- 1 high- p_T lepton (for triggering),
 - missing energy from neutrino,
 - 6 jets: 4 b-jets and 2 light jets,
 - additional jets from ISR/FSR.
- ⇒ need to find the correct $b\bar{b}$ -pair.

Large backgrounds:

- combinatorial (mis-pairing of jets),
- irreducible from $t\bar{t}b\bar{b}$ events,
- reducible from $t\bar{t} + jets$ events.

Reliable jet reconstruction and b-tagging essential for signal extraction.

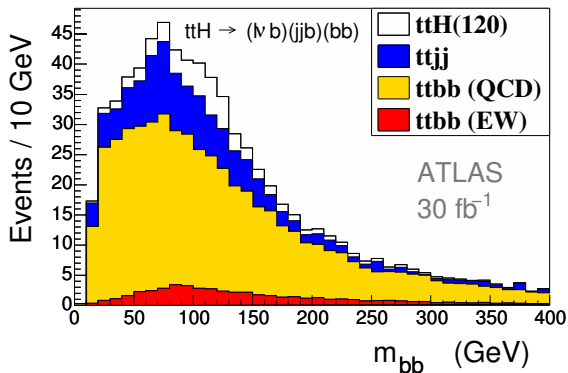


$t\bar{t}H, H \rightarrow b\bar{b}$: Signal significance

Recent degradation of the signal significance w.r.t. previous studies:

More realistic detector description. New multijet event generators.

⇒ Not a discovery channel any more.



$m_H=120$ GeV		
S	B	S/\sqrt{B}
41	218	2.8*

*Without systematic uncertainties.

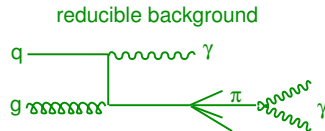
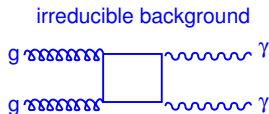
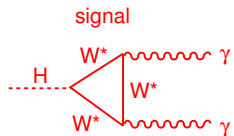
- Mass distributions have a similar shape for signal and background.
⇒ strong sensitivity to the background uncertainties.

Cross sections known only at LO - scale uncertainty of 100%.

Systematic uncertainties in the detector - jet energy, b-tagging efficiency.

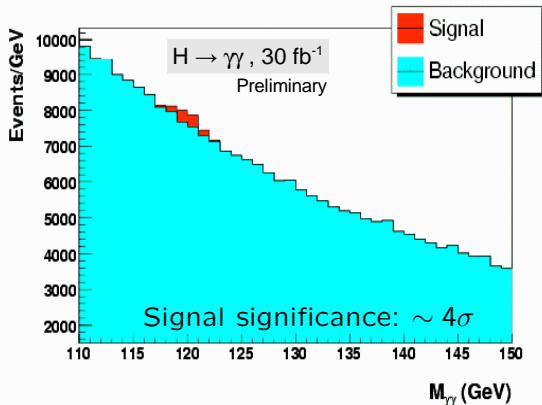


$$H \rightarrow \gamma\gamma$$



- Reducible: $qg \rightarrow q\gamma \rightarrow q\gamma\gamma$

Need an excellent γ /jet separation \Rightarrow high granularity calorimeter.



- Irreducible: $gg, q\bar{q} \rightarrow \gamma\gamma$

Smooth continuous background.



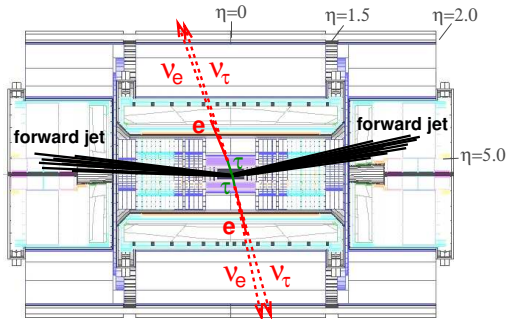
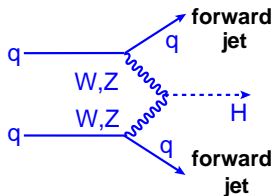
High-resolution calorimetry needed for a narrow $m_{\gamma\gamma}$ -resonance (1% mass resolution).

Vector Boson Fusion (VBF) Signatures

Recently considered as a very promising discovery signature.

First parton-level analyses for LHC introduced by D.Zeppenfeld, D.Rainwater et al. (1997).

Production rates are large enough (10-50% w.r.t gluon-gluon fusion).



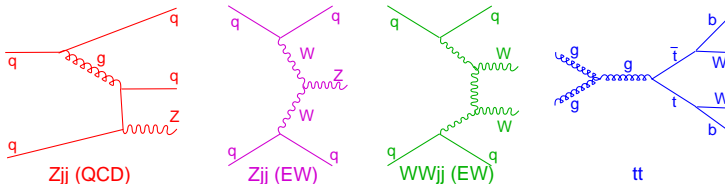
Very characteristic topology:

- Two forward jets - can be reconstructed up to $|\eta| < 4.9$.
- Large rapidity gap (no additional jets in the central region).
- Higgs decay products are central, can be used for triggering.
- Relevant decay modes: $H \rightarrow \tau^+\tau^-$, $H \rightarrow W^+W^-$.

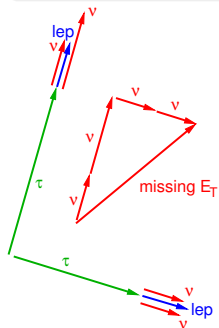
VBF $H \rightarrow \tau\tau \rightarrow (l\nu\nu l\nu\nu, l\nu\nu \tau_{jet}\nu)$

Hadron-hadron mode difficult to trigger, under investigation.

Backgrounds ($Z \rightarrow \tau\tau$ can be suppressed only in the VBF mode):



Higgs mass reconstruction possible despite of several neutrinos.



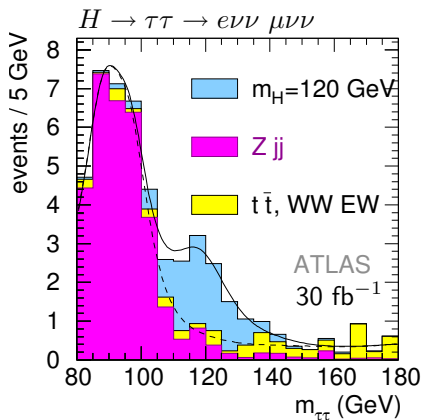
Collinearity approximation:

Decay products of highly boosted τ -leptons all fly in the original τ -direction.

$\Rightarrow \tau$ -momenta can be reconstructed.

- Higgs mass resolution $m_{\tau\tau} \sim 10\%$, mostly limited by the resolution of the missing transverse energy.

VBF $H \rightarrow \tau\tau$: Signal significance



EW/QCD $Z \rightarrow \tau\tau + jets$:
dominant contribution after all cuts.

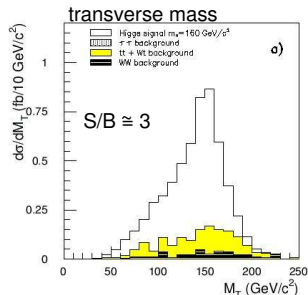
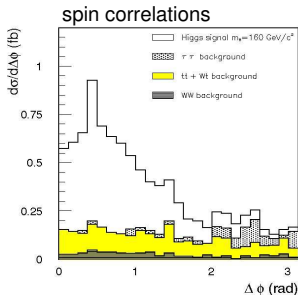
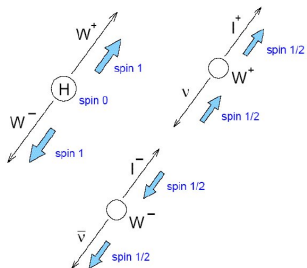
Expected uncertainty on the background rate: 5-10%.

- $m_H > 125$ GeV: Determination from the flat sidebands.
- $m_H < 125$ GeV: Normalize to Z -peak; should understand the shape.
 - ★ Relaxing selection criteria to obtain the Z -shape from data.
 - ★ Estimating $Z \rightarrow \tau\tau$ contribution from the $Z \rightarrow \mu\mu$ data.

VBF $H \rightarrow WW \rightarrow l\nu l\nu$

Event selection (similar backgrounds as for $H \rightarrow \tau\tau$):

- high transverse missing energy E_T^{miss} , $Z \rightarrow \tau\tau$ veto, τ -jet veto
- forward jet tagging, central jet veto (b -jet veto for $|\eta| < 2.5$)
- spin correlations (leptons tend to be emitted in the same direction, $\Delta\Phi_{\ell\ell} < 1.5$):



No Higgs mass reconstruction possible:

Counting the excess of signal events over the background

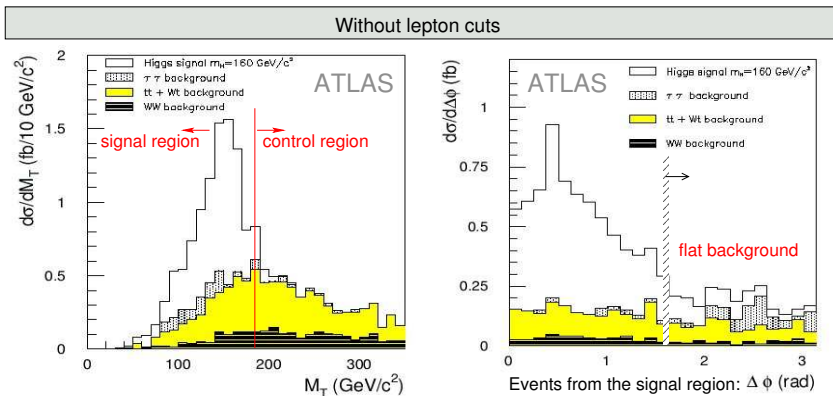
in a given region of transverse mass $m_T = \sqrt{2 \cdot p_T^{\ell\ell} \cdot E_T^{miss} (1 - \cos \Theta)}$.

⇒ Need a very good knowledge of the background distributions.

Estimation of the background from the real data:

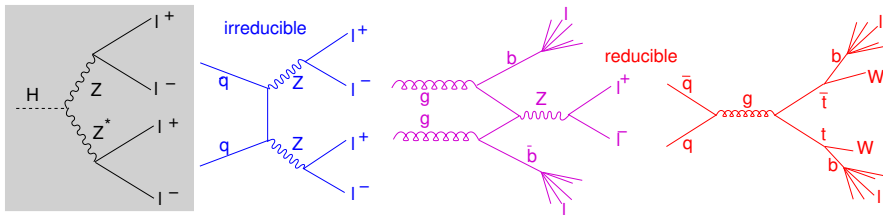
Relaxing the selection cuts on the lepton pairs,

- using m_T side-bands in the m_T -control region and
- using $\Delta\Phi_{\ell\ell}$ -region above 1.5 for events from the m_T -signal region.



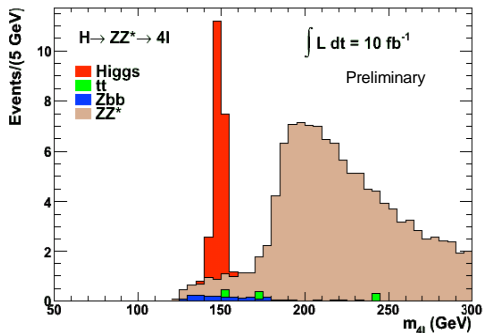
Background can be determined with 10% uncertainty.

$$H \rightarrow ZZ^{(*)} \rightarrow (l^+l^-)(l^+l^-)$$



Very clean channel.

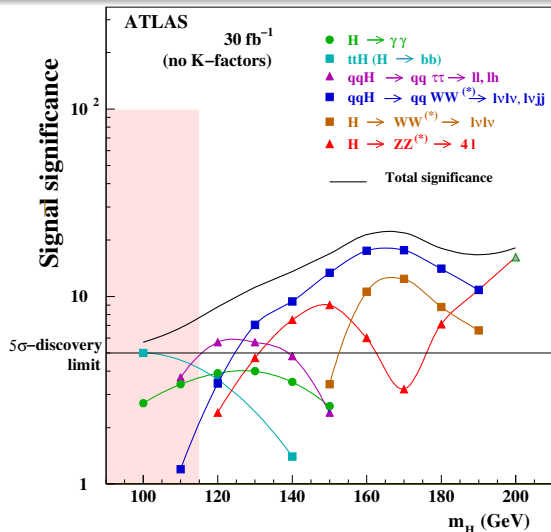
Highly sensitive to the lepton reconstruction efficiency, $\epsilon_{4l} = (\epsilon_l)^4$.



Background suppression using:

- Lepton isolation (no leptons from the jets).
- Lepton distance to a common 4-lepton vertex.
- Z-mass reconstruction.

The Higgs boson can be discovered after a few years of LHC running.



- For $m_H > 200$ GeV: discovery in the "golden" channel $H \rightarrow ZZ \rightarrow 4l$.
- For $m_H < 200$ GeV: combination of several key signatures is needed.

Thorough understanding of the background contributions and their estimation from the real data will be essential for a fast discovery.