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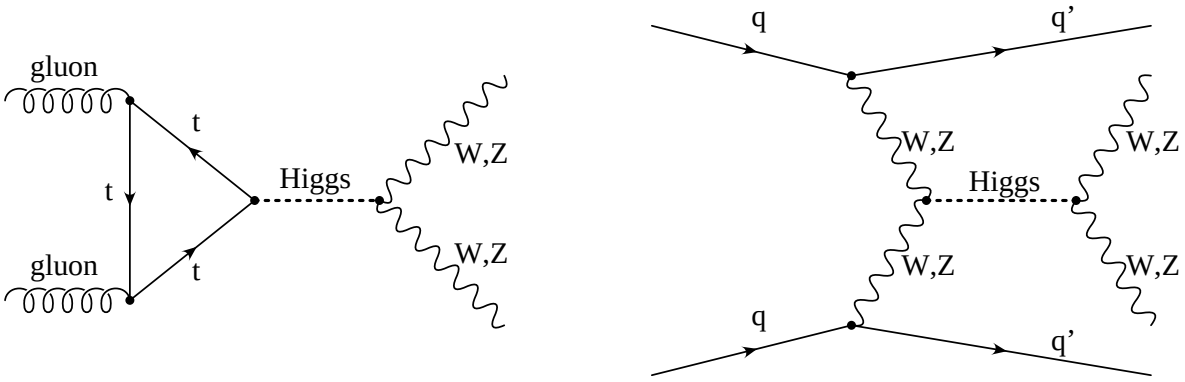
LHC Luminosity Estimates to observe the Higgs and test its properties

(some recent CMS studies)

- **Some Generalities**
- **Well known SM Higgs Signals**
- **Signals from Vector Boson Fusion**
- **Comparison and Interpretation**

Generalities

dominant LHC Higgs Production Mechanisms



1a: Want to Discover the Higgs

need to know Luminosities for 5 σ Signals as f(M_H)!
statistical Signal significance: $S/\sqrt{B}$
(for small statistics: Poisson Probabilities)

1b: What are the Discovery Signatures?

compare different signatures

2: Want to learn about Higgs Couplings?

measure Higgs Cross Sections with different signatures!
statistical cross section error: $S/\sqrt{S+B}$)!

for a recent compilation and $M_H < 200$ GeV see:
R. Kinnunen, A. Nikitenko, E. Richter-Was and D. Zeppenfeld;
Phys.Rev.D62(2000)013009 and hep-ph/0002036

use most accurate cross sections for Signal and Backgrounds

Dilemma I:

NLO Higgs Signal cross section known but many Backgrounds known only at LO

Dilemma II:

Monte Carlos with fragmentation and parton showering (many soft jets) are LO only

A way Out (in absence of anything better)

use K–factors (K= σ(NLO)/σ(LO)) if known

Signal:

$\mathrm{K}(gg \to H) \approx 1.7$ **and** $\mathrm{K}(qq \to qqH) \approx 0.95$

Backgrounds for not too fancy cuts:

$\mathrm{K}(q\bar{q} \to ZZ) \approx 1.25$ $\mathrm{K}(q\bar{q} \to WW) \approx 1.4$,
$\mathrm{K}(q\bar{q} \to WZ) \approx 1.5$, $\mathrm{K}(pp \to t\bar{t}) \approx 1.2$

in case of unknown NLO corrections:

like $gg \to \gamma\gamma(ZZ, WW)$
use K–factors from $gg \to H$ calculations!

"Known" since many years

"Inclusive" Signals (mainly from $gg \to H$):

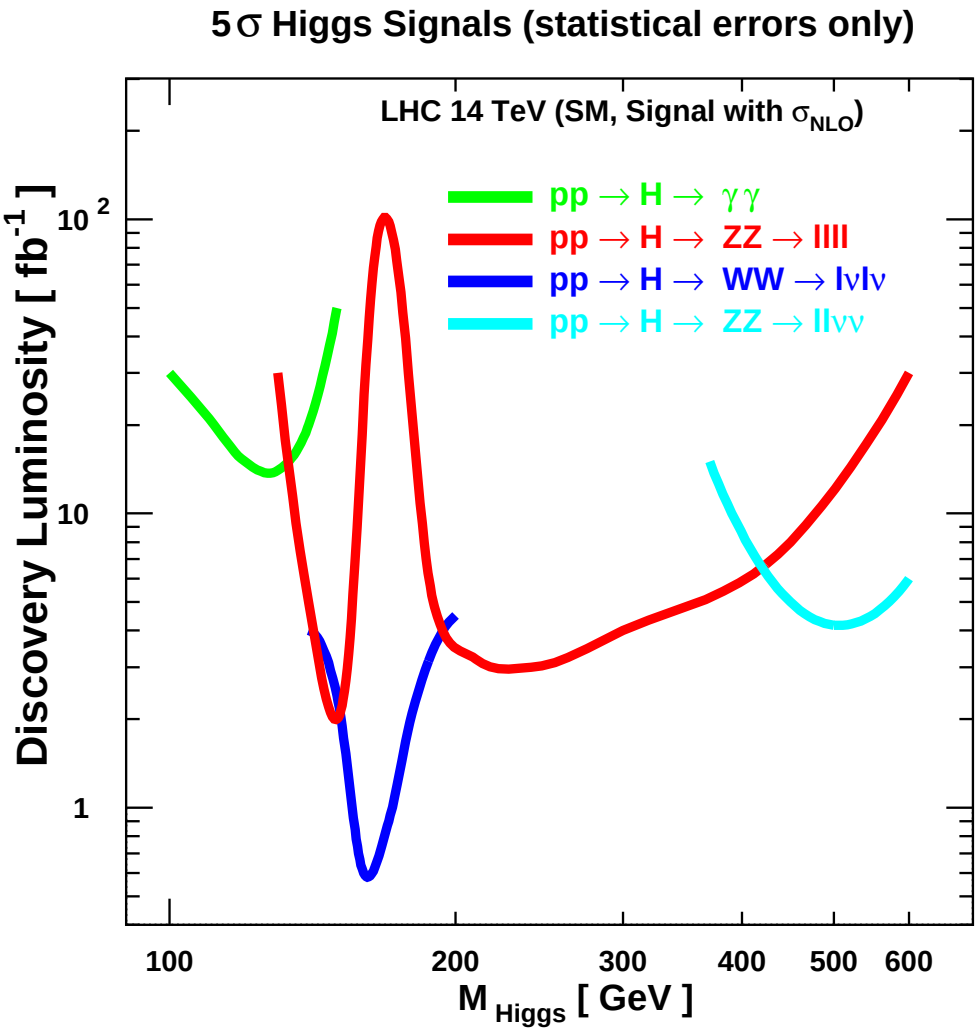
- **100 GeV** $< M_H <$ **140 GeV:** $H \to \gamma\gamma$
- **130 GeV** $< M_H <$ **155 GeV:**
  $H \to ZZ^*$ **and** $ZZ^* \to 4\ell^{\pm}$
- $M_H >$ **180 GeV:**
  $H \to ZZ$ **and** $ZZ \to 4\ell^{\pm}$
- **140 GeV** $< M_H <$ **180 GeV**
  $H \to WW \to \ell^+\nu\ell^-\bar{\nu}$

Other well established Signals:

- $M_H >$ **400 GeV:**
  $H \to ZZ \to \ell^+\ell^-\nu\bar{\nu}$
- $M_H >$ **300 GeV:**
  qqH **and** $H \to WW \to \ell^{\pm}\nu q\bar{q}$

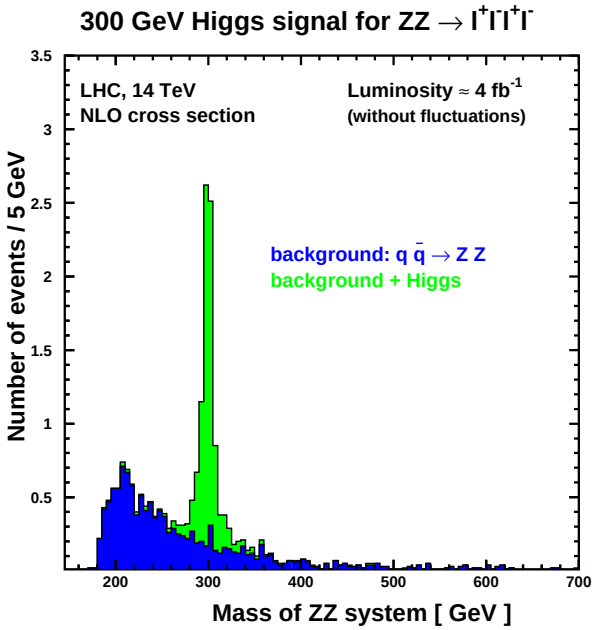
→ required LHC Luminosity for a 5 σ SM Higgs Signal in one Experiment

NLO cross sections and fast (optimistic) CMS simulations

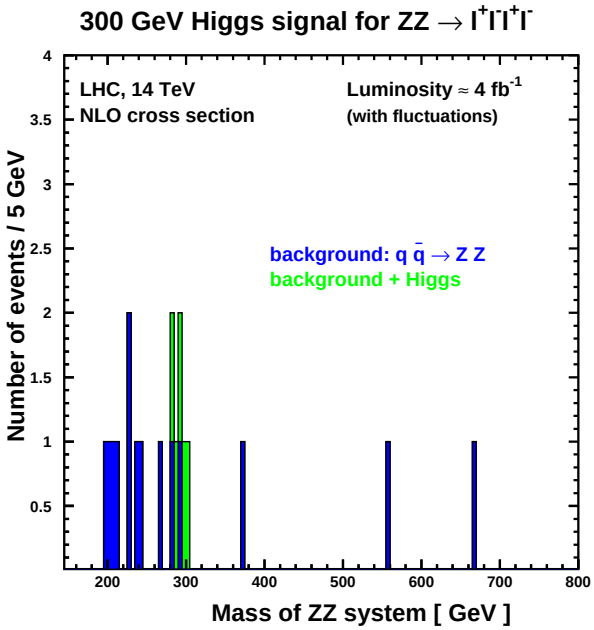


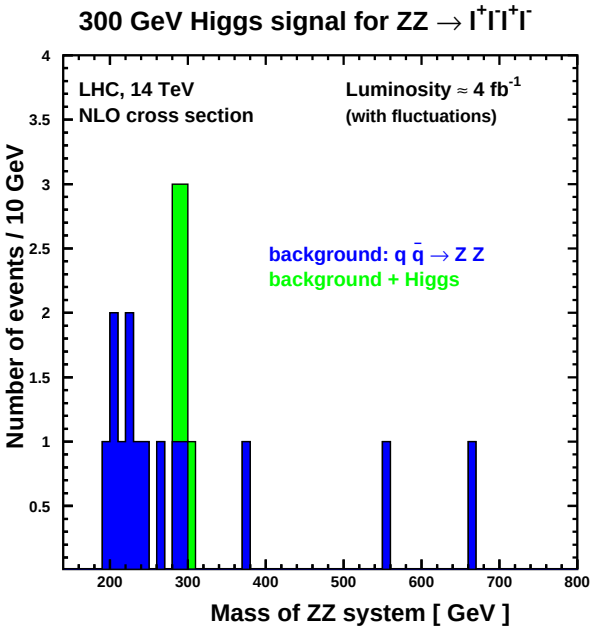
How a 300 GeV Higgs might be discovered at the LHC

an average experiment



a "realistic experiment"





Parton Level Higgs Signals:

- $M_H < 200$ GeV: $qq \to qqH \to WW \to \ell^+\nu\ell^-\bar{\nu}$

  N. Kauer, T. Plehn, D. Rainwater and D. Zeppenfeld; Phys.Lett.B503(2001)113 and hep-ph/0012351.

- $M_H < 150$ GeV: $qq \to qqH \to \gamma\gamma$

  D. Rainwater and D. Zeppenfeld; JHEP 97(1997)12:005 and hep-ph/9712271.

- $M_H < 140$ GeV: $qq \to qqH \to \tau\tau$

  D. Rainwater, K. Hagiwara and D. Zeppenfeld; Phys.Rev.D59(1999)014037 and hep-ph/9808468.

Recent CMS Studies

(a) reproduce Parton Level Studies
(b) use PYTHIA and a fast Detector simulation

- **for** $M_H < 200$ GeV: $qq \to qqH \to WW \to \ell^+\nu\ell^-\bar{\nu}$

  D. Zuercher, CMS–Note in Preparation

- **for** $M_H < 150$ GeV: $qq \to qqH \to \gamma\gamma$

  Mikhail Dubinin, CMS–Note

- **for** $M_H < 140$ GeV: $qq \to qqH \to \tau\tau$

  A. Nikitenko (this workshop)

qqH and $M_H < 200$ GeV

with PYTHIA and fast CMS Detector simulation:

- parton level results reproduced
- PYTHIA level still valuable Higgs Signals
- efficiencies ≈ 0.5 of parton level efficiencies

efficiency loss from several effects:

- leptons less isolated
- "edge" effects (p_t and η coverage) for jet tagging
- need to improve/optimize jet definition with more detailed detector simulation

new/updated studies $300 < M_H < 600$ GeV with PYTHIA and fast CMS simulation

M.D and A. Nicollerat CMS–Note in preparation and A. Nicollerat hep-ex/0103023

"consistent" simulation of lepton and jet detection/identification

Production: $gg \to H$ **and** $qq \to qqH$

Decays: $H \to ZZ$**:**

$H \to ZZ \to 4\ell^{\pm}$ **(relative rates: 1)**

$H \to ZZ \to \ell^{+}\ell^{-}\nu\bar{\nu}$ **(relative rates: 6)**

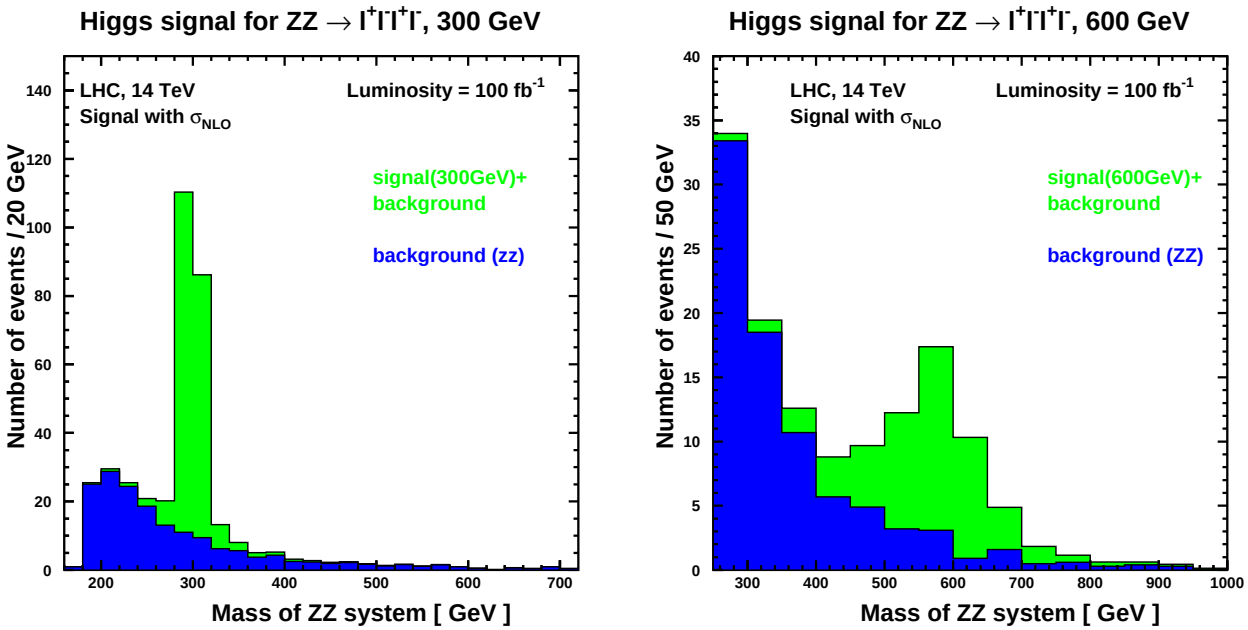
$H \to ZZ \to \ell^{+}\ell^{-}q\bar{q}$ **(relative rates: 21)**

Decays: $H \to WW$**:**

$H \to WW \to \ell\nu\ell\nu$ **(relative rates: 22)**

$H \to WW \to \ell\nu q\bar{q}$ **(relative rates: 130)**

"Standard" Signals with $H \to ZZ \to \ell\ell\ell\ell$



expected signal rates for L=100 fb^{-1}:

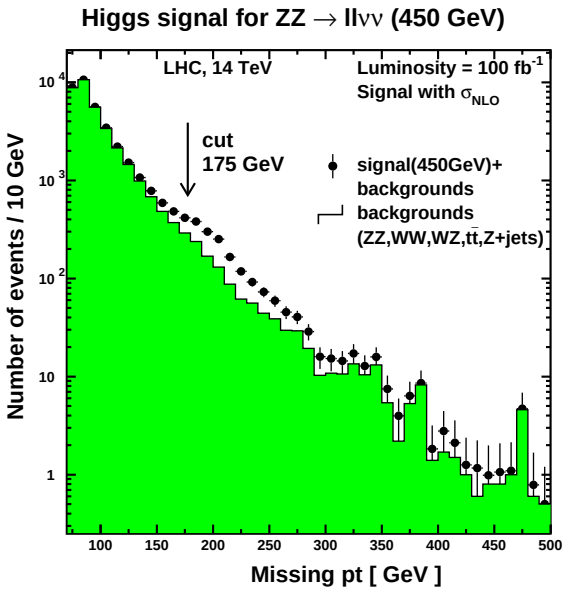
inclusive signal mainly $gg \to H$:

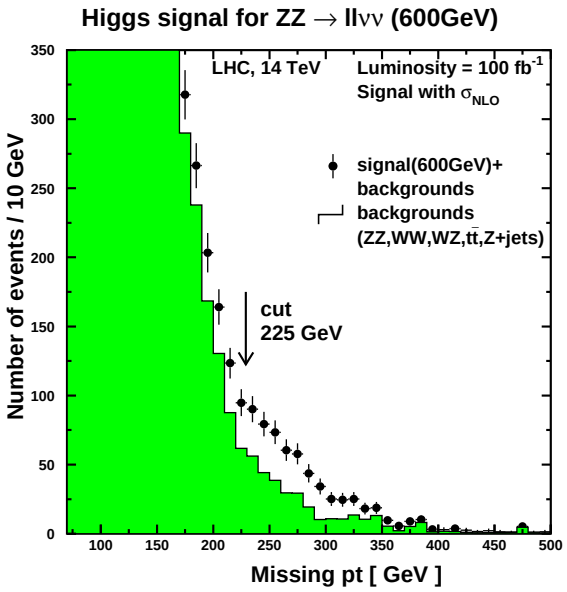
M_H=300 GeV $\approx 100 - 200$ events
M_H=600 GeV $\approx 40 - 25$ events

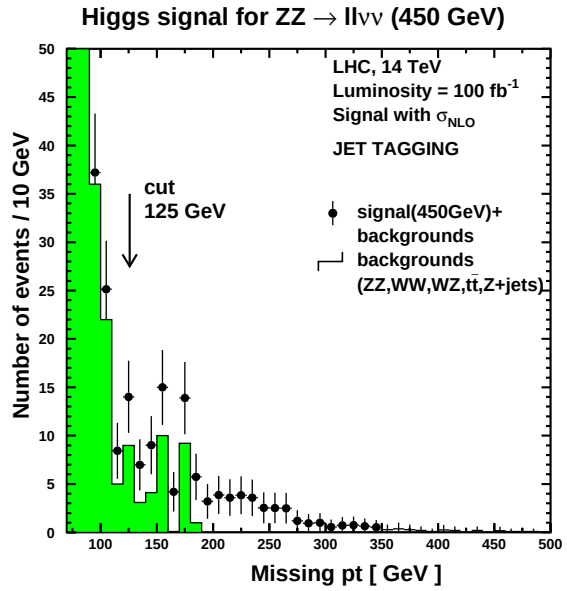
too small rates with jet tagging $qq \to qqH$:

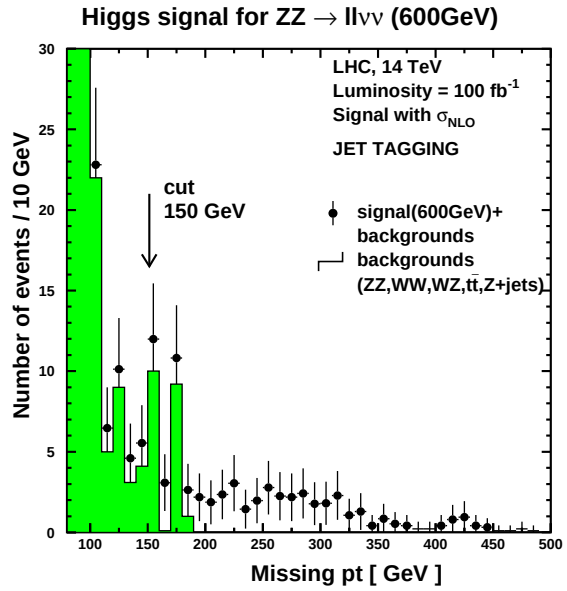
M_H=300 GeV ≈ 15 events
M_H=600 GeV ≈ 5 events

Signals with $H \to ZZ \to \ell\ell\nu\nu$









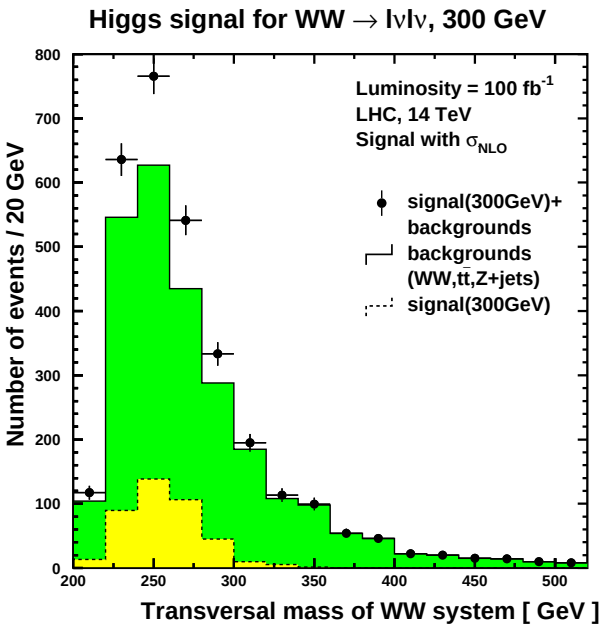
good signals for $M_H > 400$ GeV

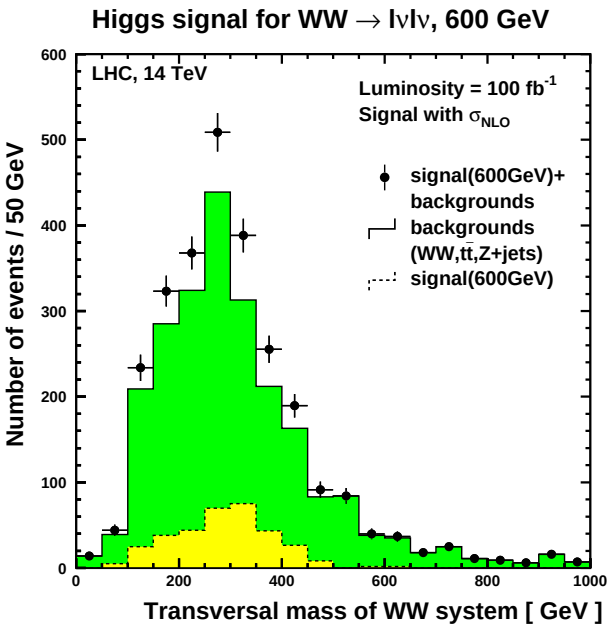
expected rates for L=100 fb^{-1}:

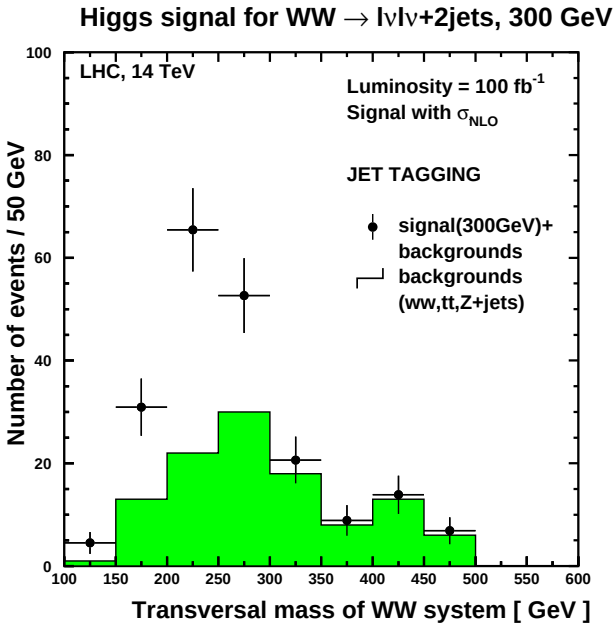
inclusive signal mainly $gg \to H$:
M_H=450 GeV $\approx$ 700 events M_H=600 GeV $\approx$ 300 events

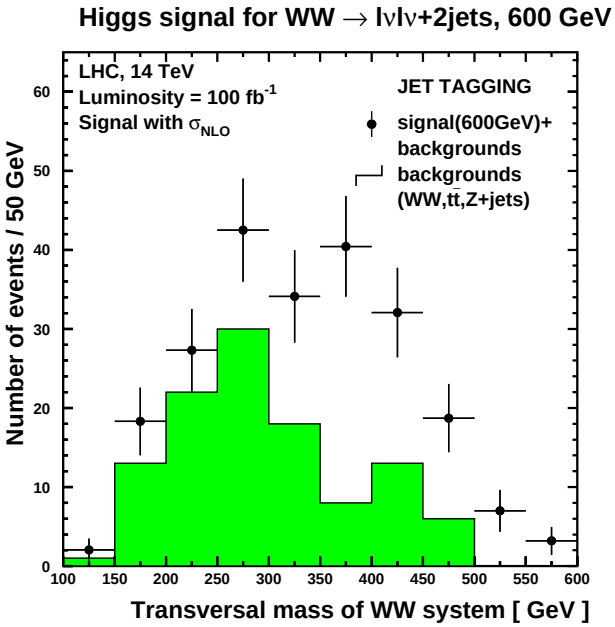
rates with jet tagging $qq \to qqH$:
M_H=300 GeV $\approx$ 50 events M_H=600 GeV $\approx$ 40 events

Signals with $H \to WW \to \ell\nu\ell\nu$







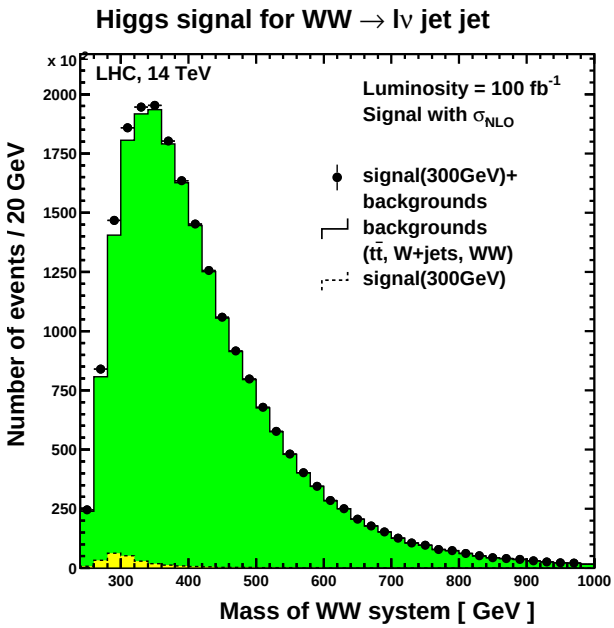


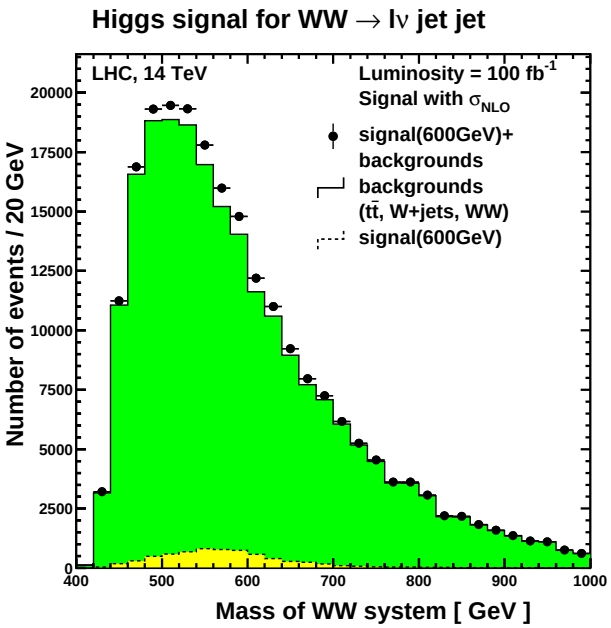
marginal signals for $gg \to H \to \ell\nu\ell\nu$

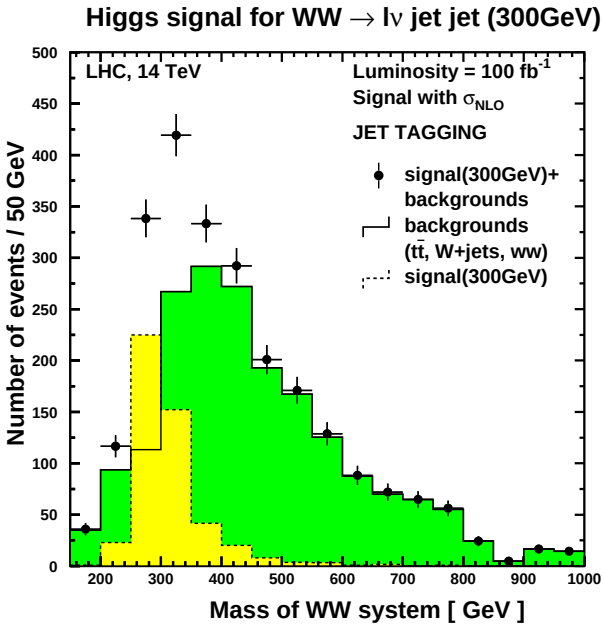
perhaps possible once M_H known!

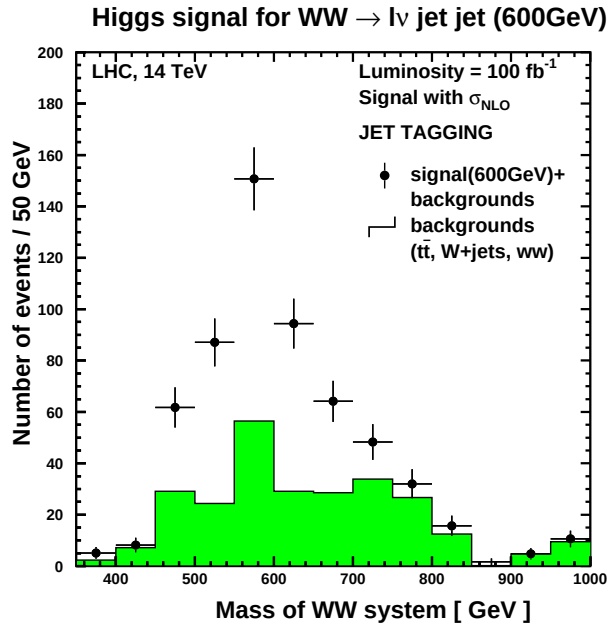
good signals with jet tagging $qq \to qqH$: M_H=300–600 GeV $\approx 100 - 150$ events

Signals with $H \to WW \to \ell\nu q\bar{q}$





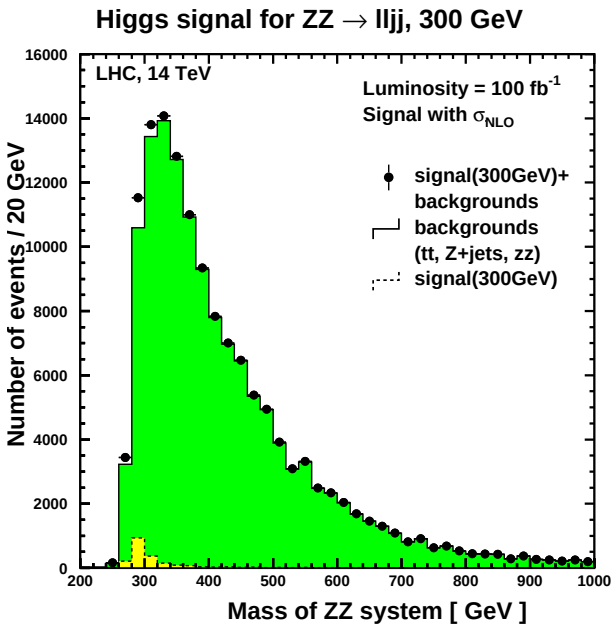


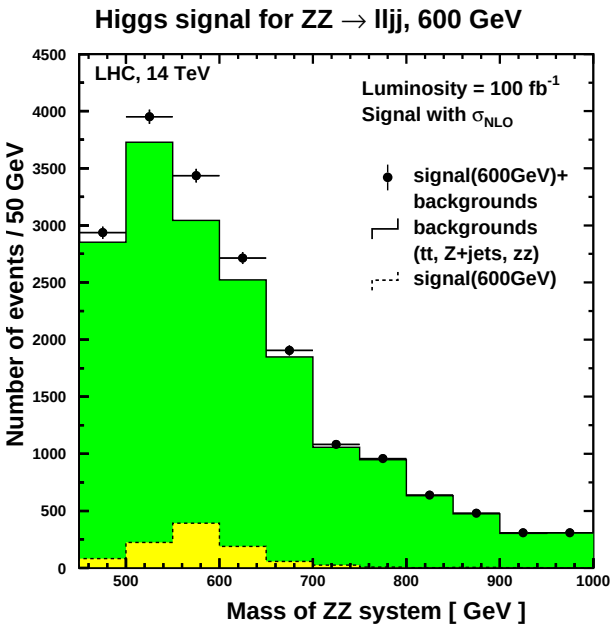


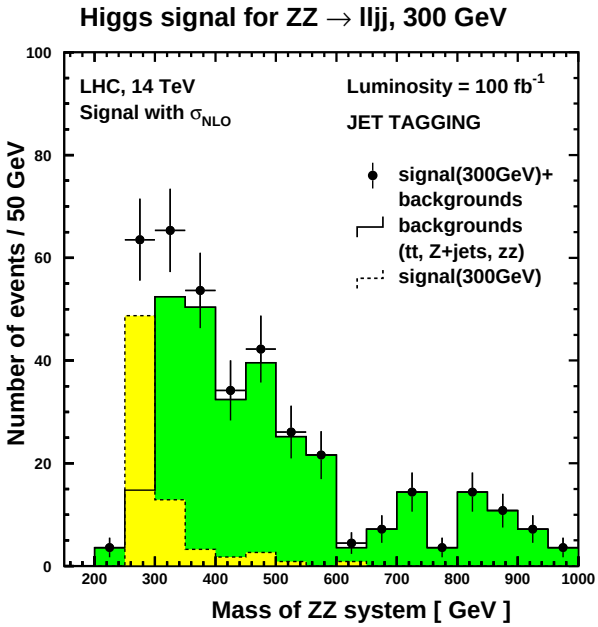
hopeless for $gg \to H \to \ell\nu q\bar{q}$

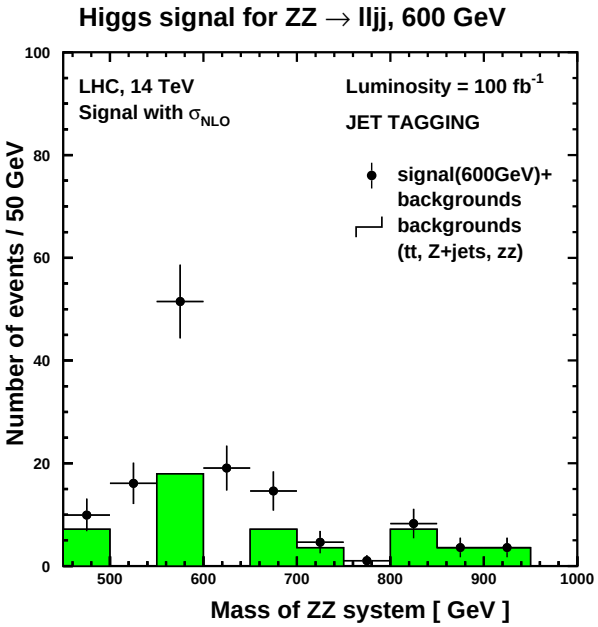
good signals with jet tagging $qq \to qqH$:
M_H=300–600 GeV $\approx$ 300 events

Signals with $H \to ZZ \to \ell\ell q\bar{q}$









hopeless for $gg \to H \to \ell\ell q\bar{q}$

good signals for jet tagging $qq \to qqH$:
M_H=300–600 GeV $\approx 50 - 80$ events

Summary

- **5 σ SM Higgs Signals:**
  few fb^{-1} for $M_H > 140$ GeV and
  20–30 fb^{-1} for $M_H < 140$ GeV
  (Strong limits already from first LHC Year!)
- **for L= 100 fb^{-1} Signals for $gg \to H$ and $qq \to qqH$**
  possible for "entire" Higgs mass range (gap 200–300 GeV)
- **Statistical cross section errors for $gg \to H$ and $qq \to qqH$**
  should reach 5–10% accuracies for L= 100 fb^{-1}
- **Measurement of BR($H \to WW$)/BR($H \to ZZ$)**
  with $\approx \pm 10$ % accuracy for L= 100 fb^{-1}